

Missing Energy Signature SUSY Searches at ATLAS

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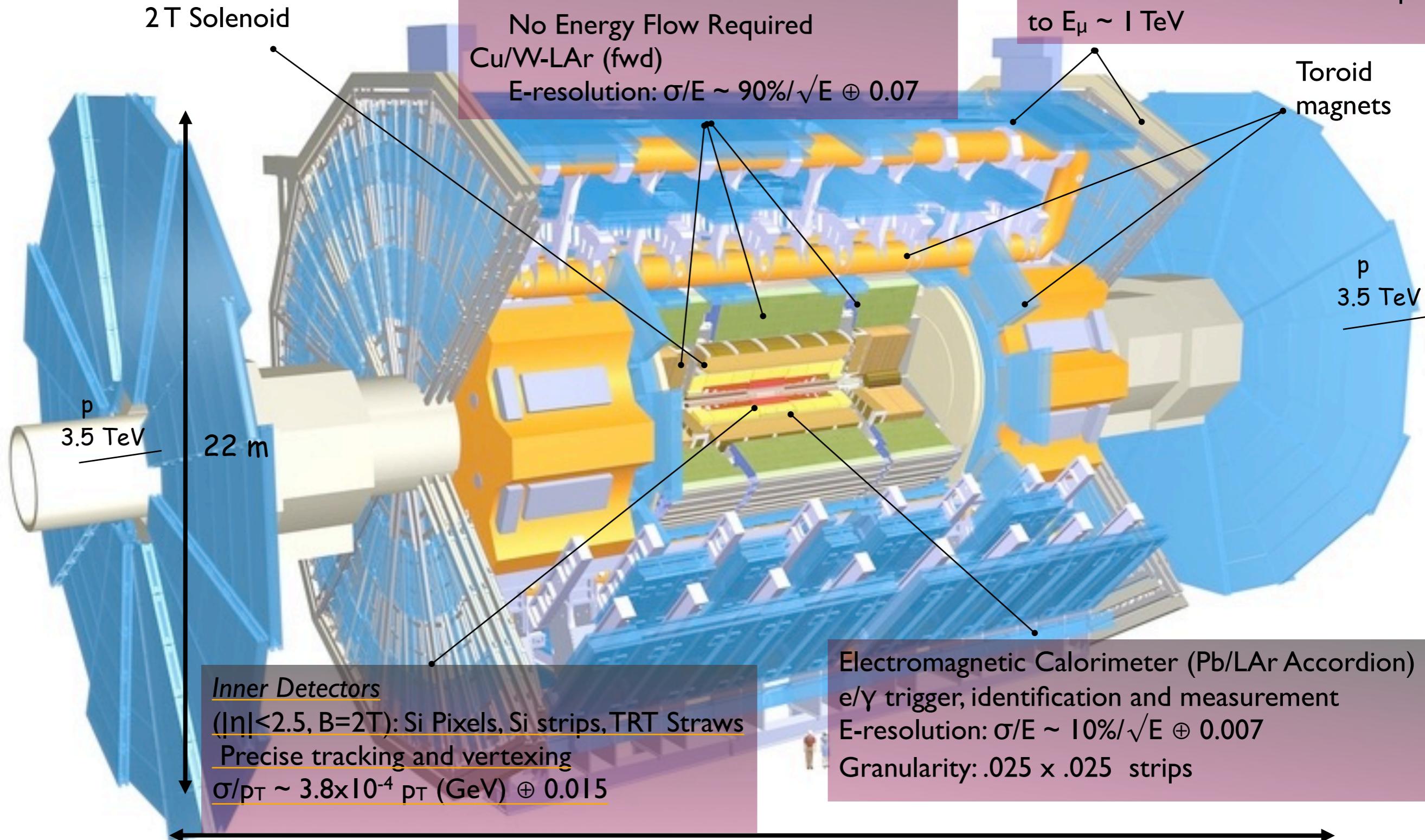
Disclaimers

- We're hopefully a few weeks away from public release of a wave of LHC results from the $>35/\text{pb}$ 2010 dataset...
 - so unfortunately, I don't have new SUSY results to show you... everything is for $\sim 70\text{-}300/\text{nb}$
 - I'll bore you with the specifics of our old analyses
 - I'll also focus on large MET-signature searches...

Plan

- Flash a few slides about ATLAS
- Search Strategy
- Backgrounds
 - Show some SM results
- Public SUSY Results

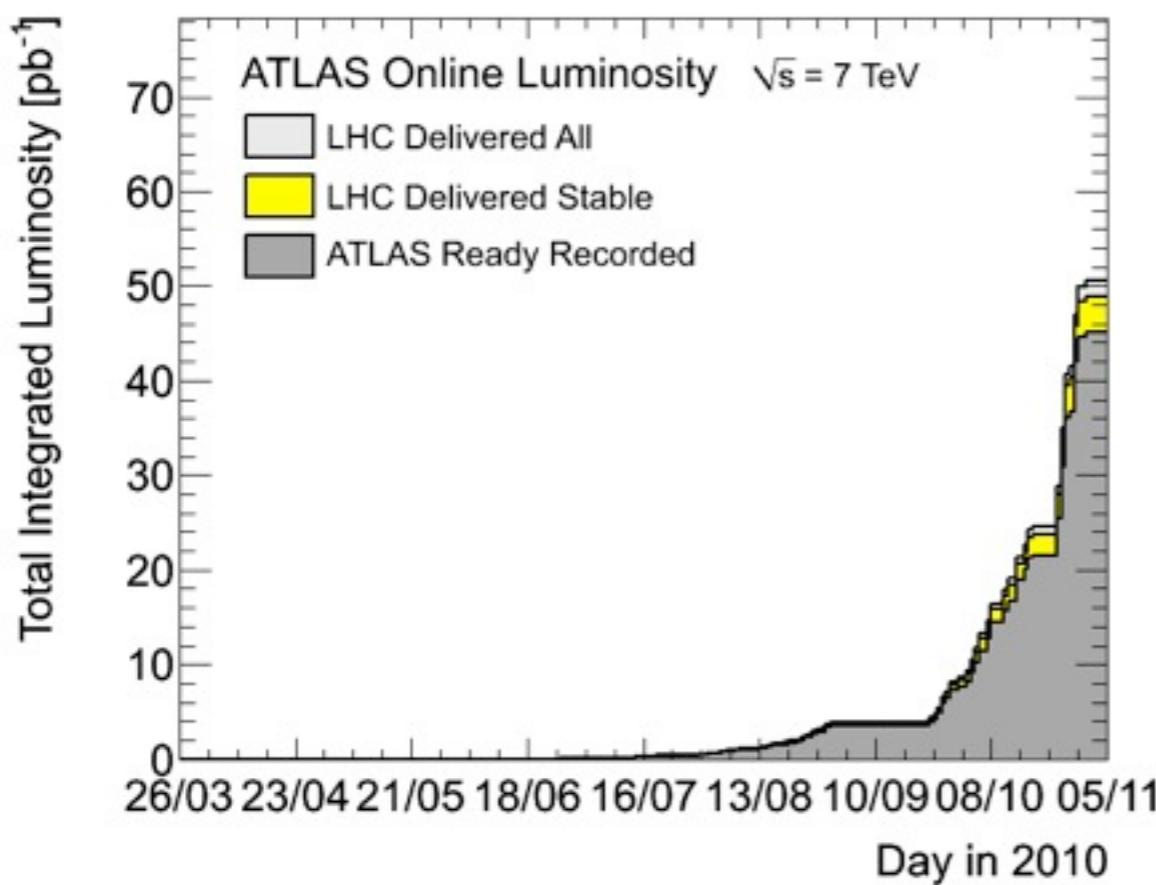
ATLAS



~ 10^8 electronic channels
3000 km of cables

46 m
Total mass ~ 7000 tonnes, installed 92 m underground.

Operations



- 48.87/pb delivered by this morning since March 30th
- van der Meer Luminosity uncertainty of 11% will go down to 5%.
- Peak Lumi: $2.07 \times 10^{32} \text{ cm}^2 \text{ s}^{-1}$
- Lumi weighted data-taking efficiency $\sim 92\%$

RECORDS

Peak Stable Luminosity Delivered	2.07×10^{32}	Fill 1440	10/10/24, 23:48
Maximum Luminosity Delivered in one fill	6304.61 nb^{-1}	Fill 1450	10/10/27, 18:39
Maximum Luminosity Delivered in one day	5983.78 nb^{-1}	Monday 25 October, 2010	
Maximum Luminosity Delivered in 7 days	24637.08 nb^{-1}	Sunday 24 October, 2010 - Saturday 30 October, 2010	
Maximum Colliding Bunches	348	Fill 1440	10/10/24, 23:48
Maximum Average Events per Bunch Crossing	3.78	Fill 1440	10/10/24, 23:48
Longest Time in Stable Beams for one fill	30.3 hours	Fill 1058	10/04/24, 01:13
Longest Time in Stable Beams for one day	22.8 hours (94.9%)	Saturday 24 April, 2010	
Longest Time in Stable Beams for 7 days	69.9 hours (41.6%)	Monday 02 August, 2010 - Sunday 08 August, 2010	
Fastest Turnaround to Stable Beams	3.66 hours	Fill 1284	10/08/14, 10:05
Fastest ATLAS Ready from Stable Beams	25.0 seconds	Fill 1285	10/08/14, 22:39
Best ATLAS Recording Efficiency for one fill	99.4 percent	Fill 1285	10/08/14, 18:26
Best ATLAS Recording Efficiency for one day ($> 10 \text{ nb}^{-1}$)	99.9 percent	Monday 16 August, 2010	
Best ATLAS Recording Efficiency for 7 days ($> 100 \text{ nb}^{-1}$)	99.7 percent	Thursday 12 August, 2010 - Wednesday 18 August, 2010	

Detector Status

- Sources of data taking inefficiency:

- Si + Muons HV Ramp
- LAr Noise Bursts
- HV Trips (LAr/Tile)

- Fraction of good data after further reprocessing is higher

Inner Tracking Detectors			Calorimeters			Muon Detectors					
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	TGC	CSC	
96.7	97.5	100	93.8	98.8	99.0	99.7	98.6	98.5	98.6	98.5	

DATA TAKING EFFICIENCY > 97%

March 30-Aug 30: Fraction of data (after stable beams declared) marked as good after 36-hours “calibration loop”, before start of reconstruction at Tier0

- Sources of channel inefficiency:

- Failing LAr Front-end Optical Transmitters (~1/month). So far 1.5%.
- Failing SCT/Pixel Back-end Optical Transmitters (~a few/week). Replace as we go.
- Failing Tile Low voltage power-supplies and Front-end interconnectivity.
- No show stoppers... spares in production.
- Repairs during Christmas 9-day/1-side access

Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	97.3%
SCT Silicon Strips	6.3 M	99.2%
TRT Transition Radiation Tracker	350 k	97.1%
LAr EM Calorimeter	170 k	98.1%
Tile calorimeter	9800	96.9%
Hadronic endcap LAr calorimeter	5600	99.9%
Forward LAr calorimeter	3500	100%
LVL1 Calo trigger	7160	99.9%
LVL1 Muon RPC trigger	370 k	99.5%
LVL1 Muon TGC trigger	320 k	100%
MDT Muon Drift Tubes	350 k	99.7%
CSC Cathode Strip Chambers	31 k	98.5%
RPC Barrel Muon Chambers	270 k	97.0%
TGC Endcap Muon Chambers	320 k	98.6%

CHANNEL EFFICIENCY > 97%

Search Strategy

Searching for New Physics

- Standard things to look for:
 - Resonances, deviations in angular distributions, cross-sections etc...
 - Heavier W/Z's (large range of theories with W', Z')
 - High multiplicity final-states (eg black holes)
 - Exotic signatures (eg long-lived particles)
 - Large Missing Energy
- Many searches are motivated by the idea that new particles are copiously (strongly) produced at the LHC with decay chains that end in a DM candidate
 - Inclusively search for Large MET with Jets and/or leptons signatures.
 - Covers a large range of new physics models... including R-Parity Conserving SUSY, UED, ...
 - constitutes the primary LHC SUSY search strategy
 - The reason we consider these SUSY searches, is that it covers SUSY so well
 - there is a long history of using SUSY models and separating SUSY from “Exotics”... but we are beginning to move towards model independence.

Inclusive Signatures

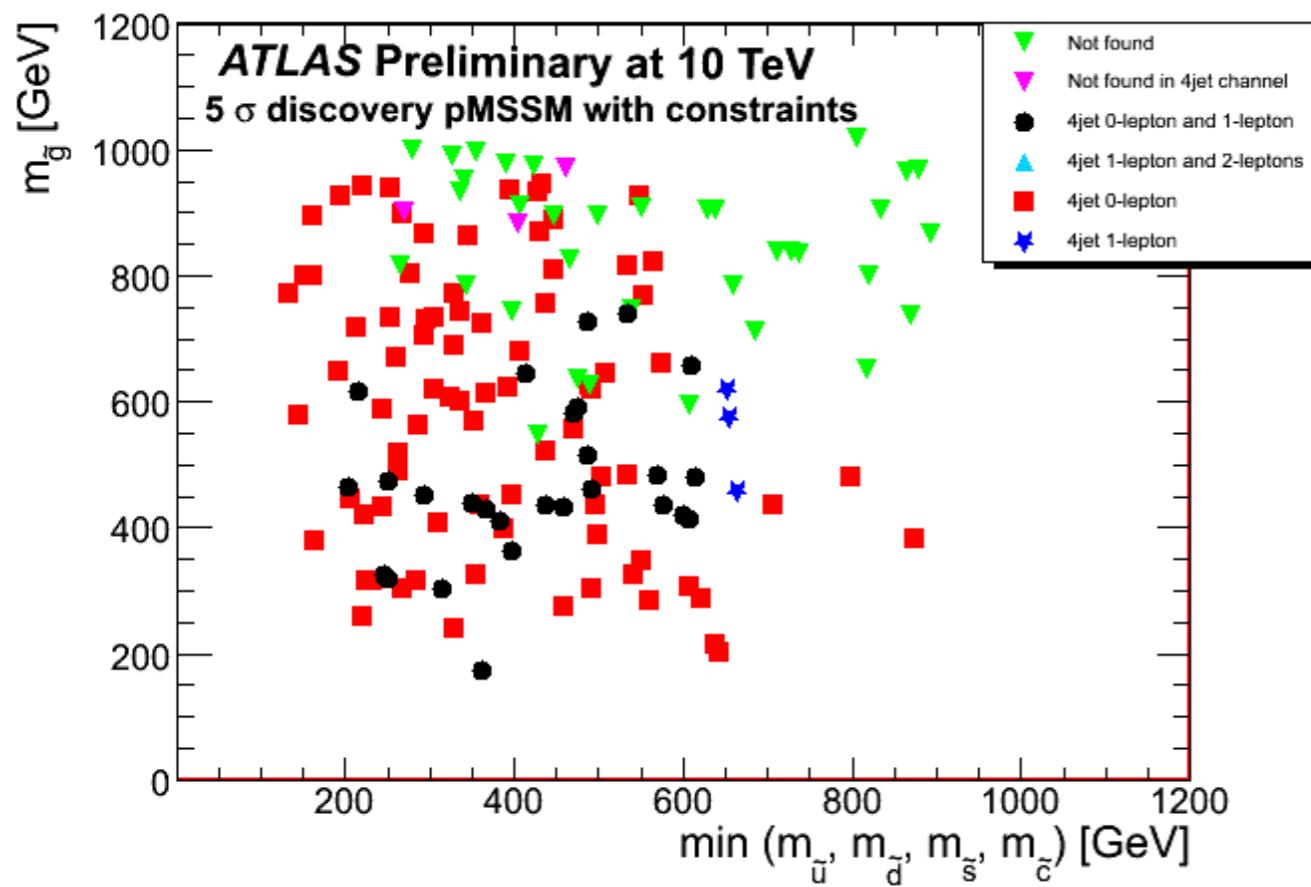
Signature	Motivating Model(s)	Comments
1 Jet + 0 Lepton + MET	<ul style="list-style-type: none"> Large Extra Dim (ExoGraviton) <ul style="list-style-type: none"> strong qG production, G propagate in extra Dim Planck Scale is MD in $4+\delta$ dim Normal Gravity $\gg R$ SUSY <ul style="list-style-type: none"> $qg \rightarrow ISR + 2 \text{ Neutralino or squark} + \text{Neutralino}$ 	<ul style="list-style-type: none"> Not primary discovery channel for SUGRA, GMSB, AMSB... but helps in characterization Possible leading discovery for neutralino NLSP with nearly degenerate gluino
2,3,4 Jet + 0 Lepton + MET	<ul style="list-style-type: none"> Squark/gluino production $\text{squark} \rightarrow q + \text{LSP}$, $\text{gluino} \rightarrow q + \text{squark} + \text{LSP}$ 	<ul style="list-style-type: none"> Possible leading squark/gluino discovery channel Must manage QCD bkg
2,3,4 Jet + 1 Lepton + MET	<ul style="list-style-type: none"> squark/gluino production with cascades which include electroweak (or partner) decays high $\tan \beta$ leads to more T's 	<ul style="list-style-type: none"> Lepton requirement suppresses QCD T's partially covered by e/μ
2 lepton + MET	<ul style="list-style-type: none"> Same sign: gluino cascade can have either sign lepton... squark/gluino prod can produce same sign. Opposite sign: squark/gluino decay dedicated by Z (or partner) Same flavor: 2 leptons from same sparticle cascade must be same flavor 	<ul style="list-style-type: none"> Reduced SM backgrounds for same sign Opposite Sign-Flavor Subtraction
3 lepton + MET	<ul style="list-style-type: none"> SUSY events ending in Chargino/neutralino pair decays Weak Chargino/Neutralino production Exotic sources 	<ul style="list-style-type: none"> Low SM bkg
2 photon + MET	<ul style="list-style-type: none"> GMSB models with gravitino LSP and neutralino or stau NLSP UED- each KK partons cascade to LKP which decays to graviton + γ 	<p style="text-align: center;">~ a dozen searches</p>

Selections & Model Dependence

- Some worry that the concentration on SUSY breaking models (specifically mSUGRA) obscured our sensitivity to other models...
- While SUSY is our back-drop, the selections used in our signature-based searches are *in nearly all cases* motivated by
 - trigger
 - control of instrumental backgrounds
 - avoidance of SM dominated regions
- Signal models are not influencing our selections...
- It is usually only in the interpretation (ie putting limits) that models are assumed
 - here, we have been gradually adopting simplified models of new physics which are less model dependent.
- Note that it is possible that optimizing for specific models/parameters would provide better sensitivity in specific regions ...
 - If we can identify problematic regions, we can make it up with dedicated searches...

Coverage

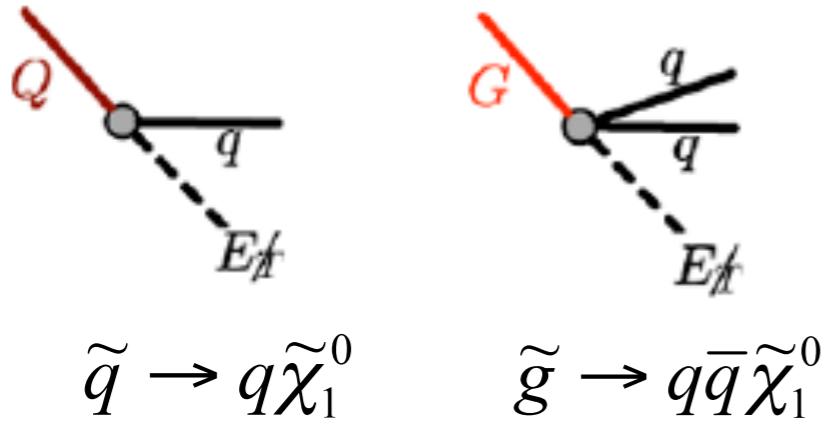
Number of analyses	Flat, 1 fb^{-1}	Flat, 10 fb^{-1}
0	0.56754	0.36796
1	1.3458	0.98841
2	3.396	2.5141
3	13.175	10.635
4	22.014	18.455
5	9.5512	10.3
6	15.227	16.929
7	20.081	17.697
8	7.6394	11.75
9	3.9205	6.3569
10	2.0825	2.7943
11	1.0013	1.2116



- pMSSM (Conley, Gainer, Hewett, Le, Rizzo arXiv: 1009.2539):
 - 19 dim reduction of MSSM, sampled with masses $< 1 \text{ TeV}$
 - 98.8% discovered by at least one ATLAS search with 10/fb of 14 TeV data.
- ATLAS looked at pMSSM, assuming 200/pb of 10 TeV
 - Green is not found... rest is found
 - Closer look showed that not found because:
 - upper/right- low x-section
 - didn't consider b-jets channel
 - low p_T jets... difficult to see!
 - So it appears that ATLAS coverage is very good... we don't miss much because of model bias.
 - Exact same searches give similar sensitivity to UED

Topology-based Models

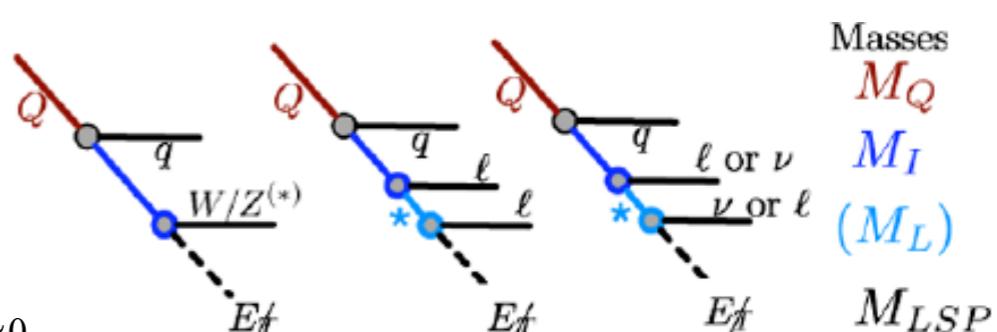
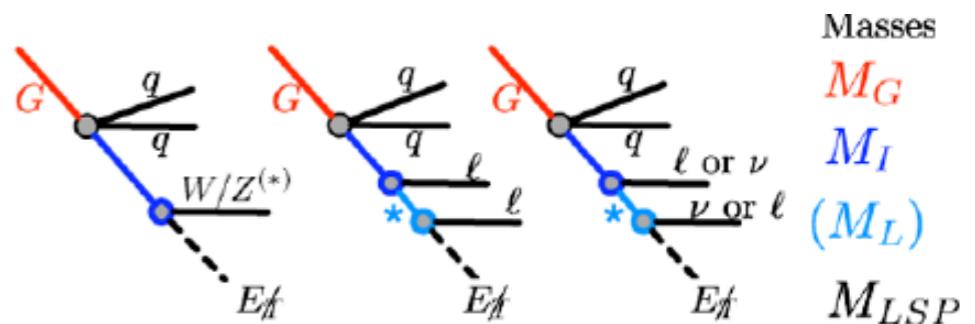
- Instead of using a SUSY breaking model with a manageable set of GUT-scale parameters, concentrate on simplified models of specific topologies that can lead to a given signature and the associated TeV scale parameters



- For example we consider 3 “topology-motivated” grids for Jet+MET signature:
 - $m(\text{gluino})$ vs $m(\text{quark})$ assuming light LSP (0, 50, 100 GeV)... other gauginos heavy
 - $m(\text{gluino})$ vs $m(\text{chi0})$, assuming other masses high
 - $m(\text{squark})$ vs $m(\text{chi0})$, assuming other masses high

- 1 lepton + Jet + MET grids are more complicated:
 - $M(\text{sq}) - M(\text{chi2/chi+-}) - M(\text{chi1})$ (heavy gluino)
 - $M(\text{sq}) - M(\text{chi2/chi+-}) - M(\text{sl}) - M(\text{chi1})$ (heavy gluino)
 - $M(\text{gl}) - M(\text{chi2/chi+-}) - M(\text{chi1})$ (heavy squark)
 - $M(\text{gl}) - M(\text{chi2/chi+-}) - M(\text{sl}) - M(\text{chi1})$ (heavy squark)
- And assuming chi1 is ~bino, chi2 is ~wino, $M(\text{chi2})=M(\text{chi+-})$

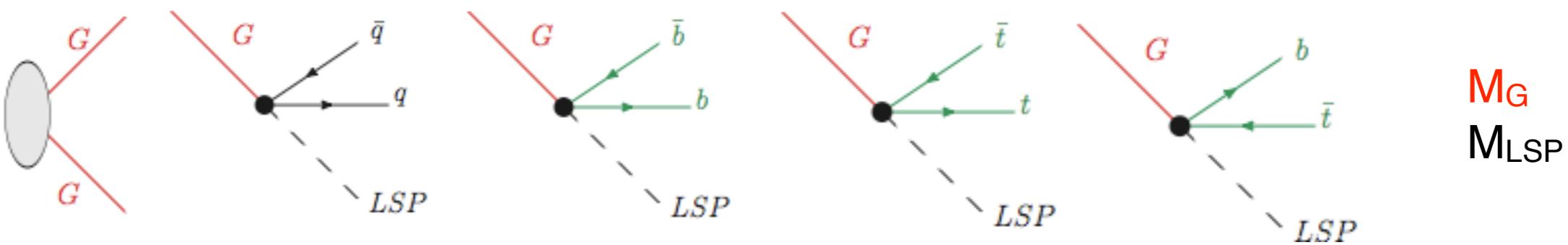
$$\begin{array}{ccccccc} \tilde{g} \rightarrow q \bar{q} \tilde{\chi}_2^0 & \tilde{q} \rightarrow q \tilde{\chi}_2^0 & \tilde{\chi}_2^0 \rightarrow (Z^{(*)}/h) \tilde{\chi}_1^0 & \tilde{\chi}_2^0 \rightarrow \tilde{l} l \rightarrow l l \tilde{\chi}_1^0 \\ \tilde{g} \rightarrow q \bar{q}' \tilde{\chi}_1^\pm & \tilde{q} \rightarrow q' \tilde{\chi}_1^\pm & \tilde{\chi}_1^\pm \rightarrow W^{(*)} \tilde{\chi}_1^0 & \tilde{\chi}_1^\pm \rightarrow \tilde{l} \nu \rightarrow l \nu \tilde{\chi}_1^0 \end{array}$$



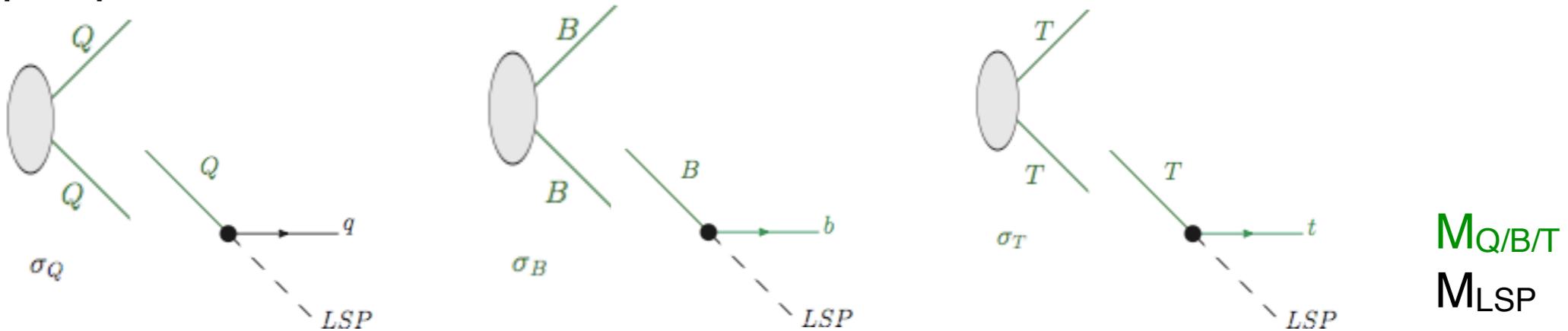
Heavy Flavor Topologies

- Heavy Flavors is a good example of where Topological approach can help develop the search strategy.
- Heavy flavor topologies:

- eg gluino pair prod:



- eg squark pair prod: σ_Q



- Difficult to turn a search in a specific signature into a limit on topologies parameters because topology to signature mapping is non-trivial... must weigh, etc
- But by studying how the kinematics of the topologies change with parameters, we can make sure that they are at least covered by our search strategy.

Heavy Flavor Analysis Strategy

- Studying topologies show that
 - Observables are mostly dependent on $\Delta M(\sim g, \chi^0)$. Squark/gluino mass only effect x-section
 - Hard to create one analysis with good sensitivity in all signatures.
- Example strategy:
 - **Case I: 2 high pT b-jets + large MET**
 - Can cover topologies
 - $B \rightarrow b + \text{LSP}$ or $T \rightarrow t + \text{LSP}$ w/ large $\Delta M(\sim g, \chi^0)$
 - $G \rightarrow tb + \text{LSP}$ large ΔM
 - Possibly low jet multiplicity
 - Trigger: MET+jets, b-jets
 - **Case 2: 2 low pT b-jets + low MET**
 - Extends into cases with low pT 3rd, 4th b-jet
 - Can cover topologies (generally low ΔM)
 - $B \rightarrow b + \text{LSP}$ or $T \rightarrow t + \text{LSP}$ w/ small ΔM
 - $G \rightarrow 2b/2t2b + \text{LSP}$ (small ΔM) and $G \rightarrow 2t + \text{LSP}$
 - Low pT b-tag optimization
 - Event variables
 - Trigger: b-jets, MET+jets
 - **Case 3: 4 high pT b-jets + large MET**
 - Generally 4b signatures with high ΔM
 - Can cover topologies: Gluino- $\rightarrow 4b$ and $2t2b$
 - High b-tag multiplicity ($\geq 3?$, $4?$)
 - Small backgrounds?
 - Trigger: b-jet, MET+jets, multijets
 - **Case 4: 4 low pT b-jets + small MET**
 - Generally 4b signatures with low ΔM
 - Can cover topologies: Gluino- $\rightarrow 4b$, $2t2b$, $4t$
 - High b-tag multiplicity ($\geq 3?$, $4?$)
 - Small backgrounds?
 - Trigger: b-jets, MET+jets

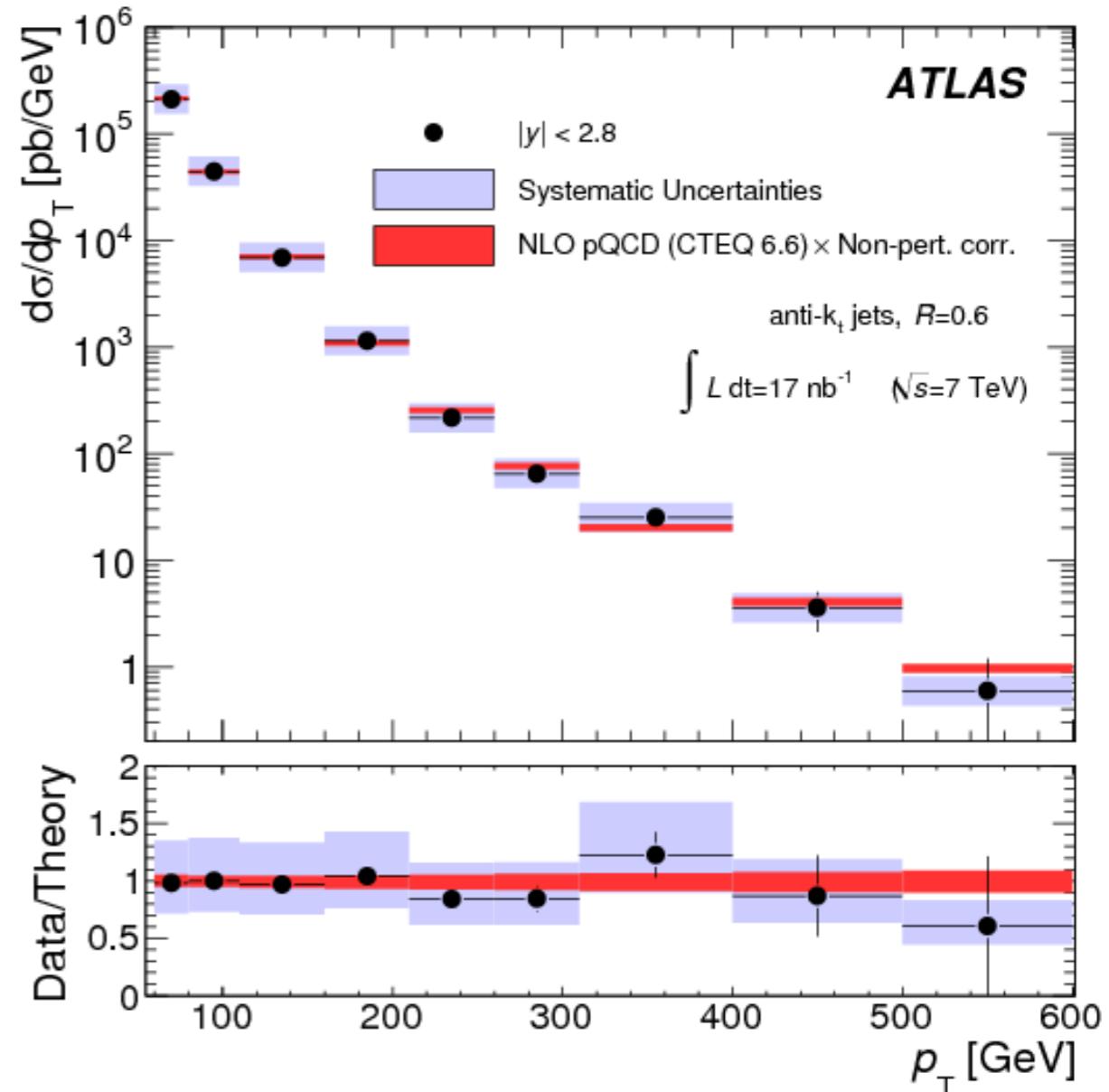
Backgrounds

Backgrounds

- Primary concerns:
 - QCD: reducible background which is generally under control (ie brought to negligible levels) with MET cut, lepton or b-jet requirement, and/or topological variables... but we still need to estimate.
 - $W/Z+Jet$
 - $Z(\rightarrow\text{vv})+Jet$: irreducible background that must be estimated.
 - $T\bar{p}$: significant for higher multiplicities signatures
- We strive for data-driven background estimations...
- In practice, most SUSY backgrounds are estimated with semi-data-driven methods
 - MC normalized to data in control region then extrapolated to signal region... ie we are relying on MC shapes.
 - Later I'll show our simple techniques from summer... stay-tuned for more sophisticated approaches in next few weeks.
- Nonetheless our first SM measurements show that (N)NLO predictions (extrapolations from 2 TeV) are very reliable...
 - This wasn't obvious 1 year ago... so lets take a quick look at how NLO calculations are doing.

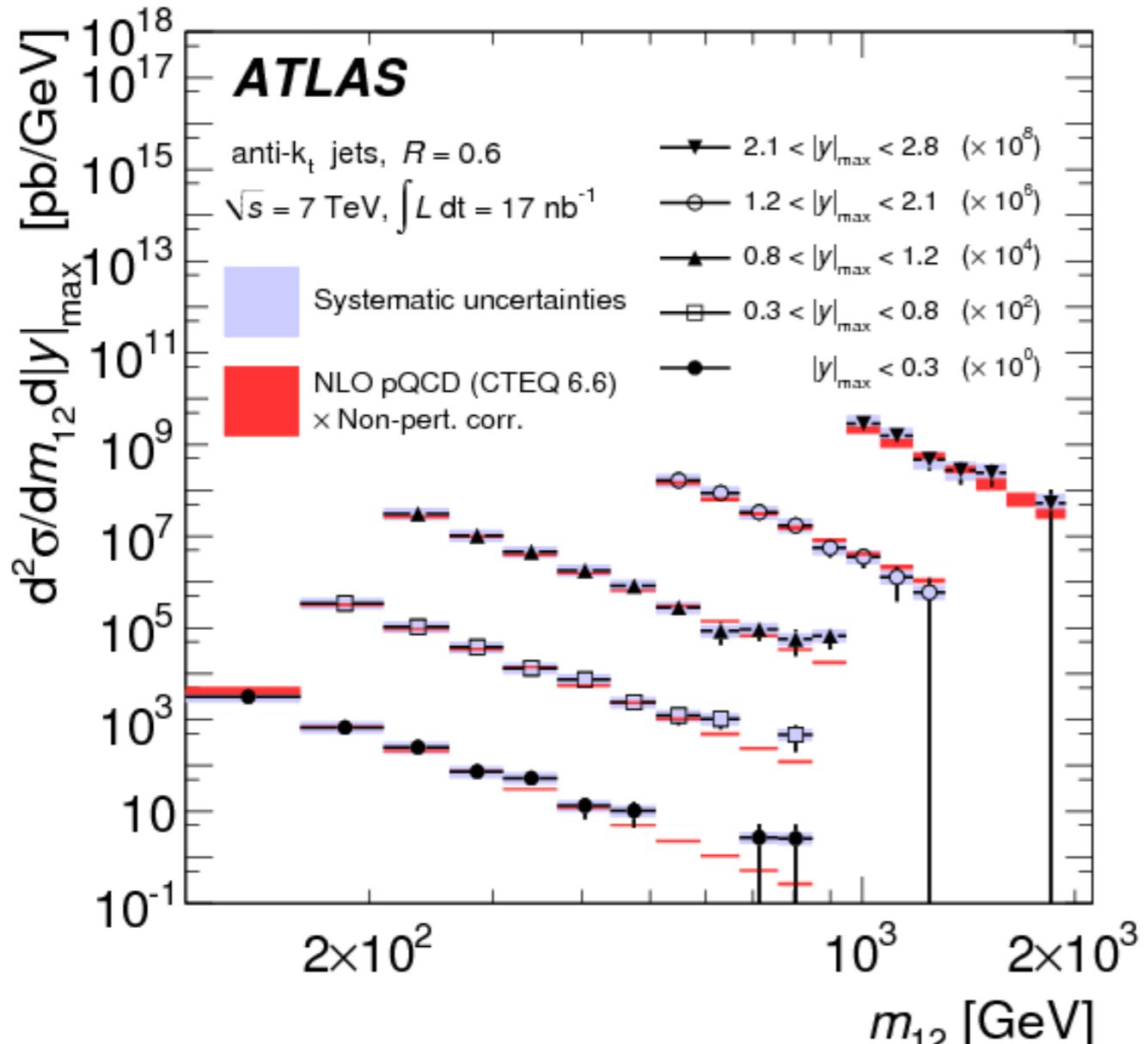
Inclusive Jet x-section

- Measured jets corrected to particle-truth level (incl μ and ν) using parton-shower MC (Pythia, Herwig)
- Results compared to NLO QCD prediction after corrections for hadronization and underlying event
- Theoretical uncertainty: $\sim 20\%$ (up to 40% at large $|y_j|$) from variation of PDF, α_s , scale (μ_R , μ_F)
- Experimental uncertainty: $\sim 30\text{-}40\%$ dominated by JES (known to $\sim 7\%$,)
- Luminosity uncertainty(11%) not included
- *Good agreement data-NLO QCD over 5 orders of magnitude*

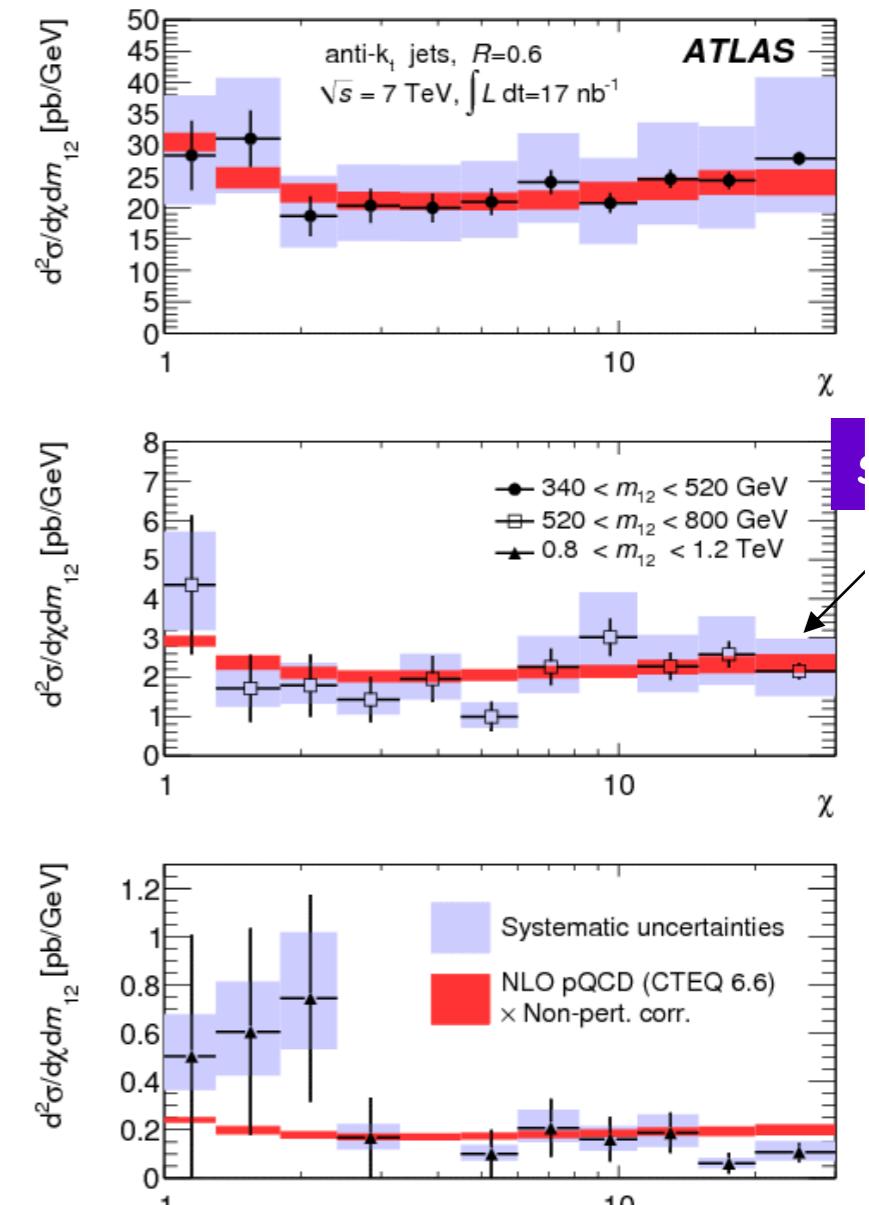


All Jets from events with at least
one Jet $p_T > 60 \text{ GeV}, |y_j| < 2.8$

Dijet x-section



Di-jet cross-section vs mass

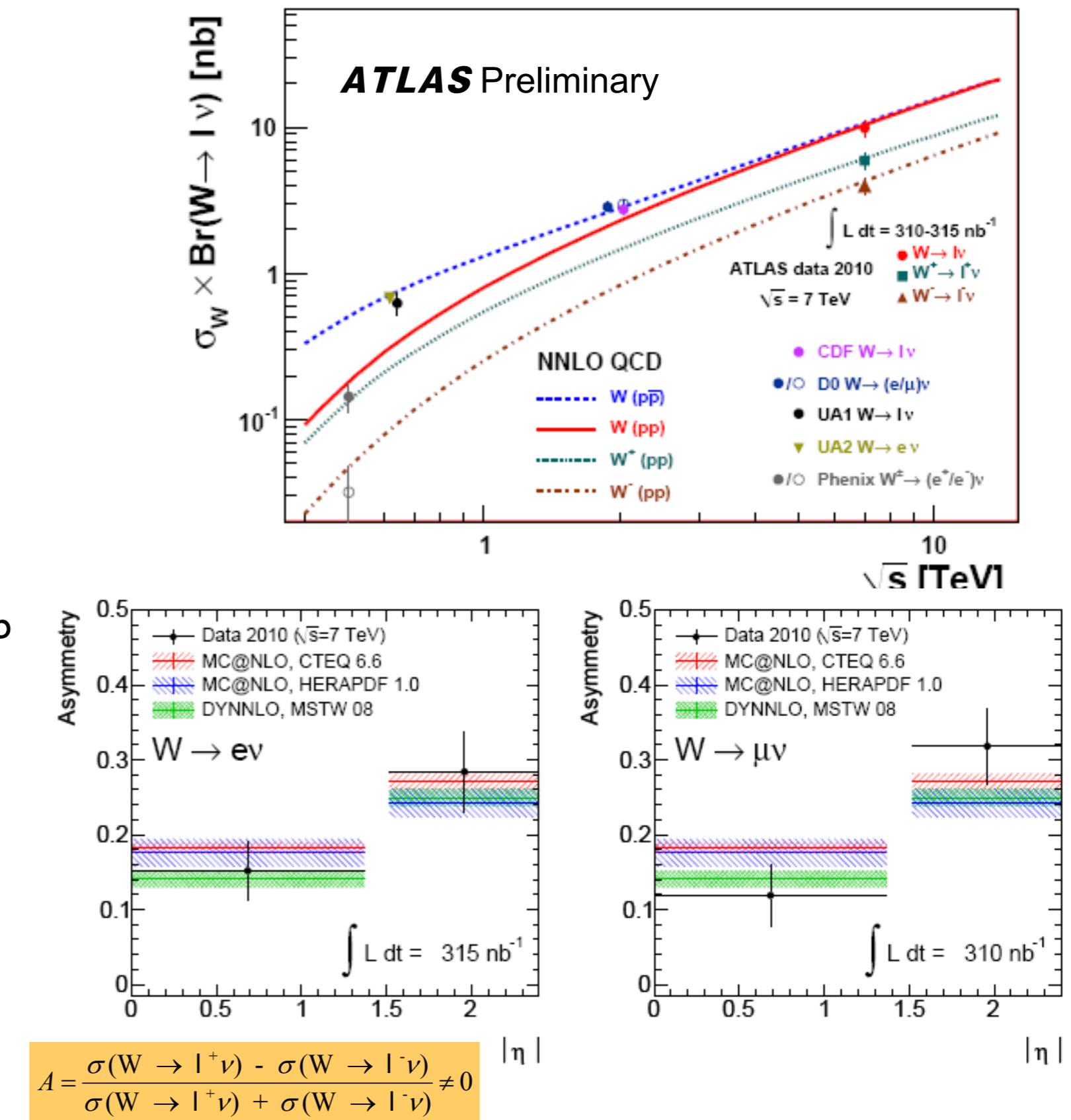


Di-jet cross-section vs angle

- Leading Jet $p_T > 60 \text{ GeV}$, sub-leading $> 30 \text{ GeV}$
- *Good agreement.*

W x-section

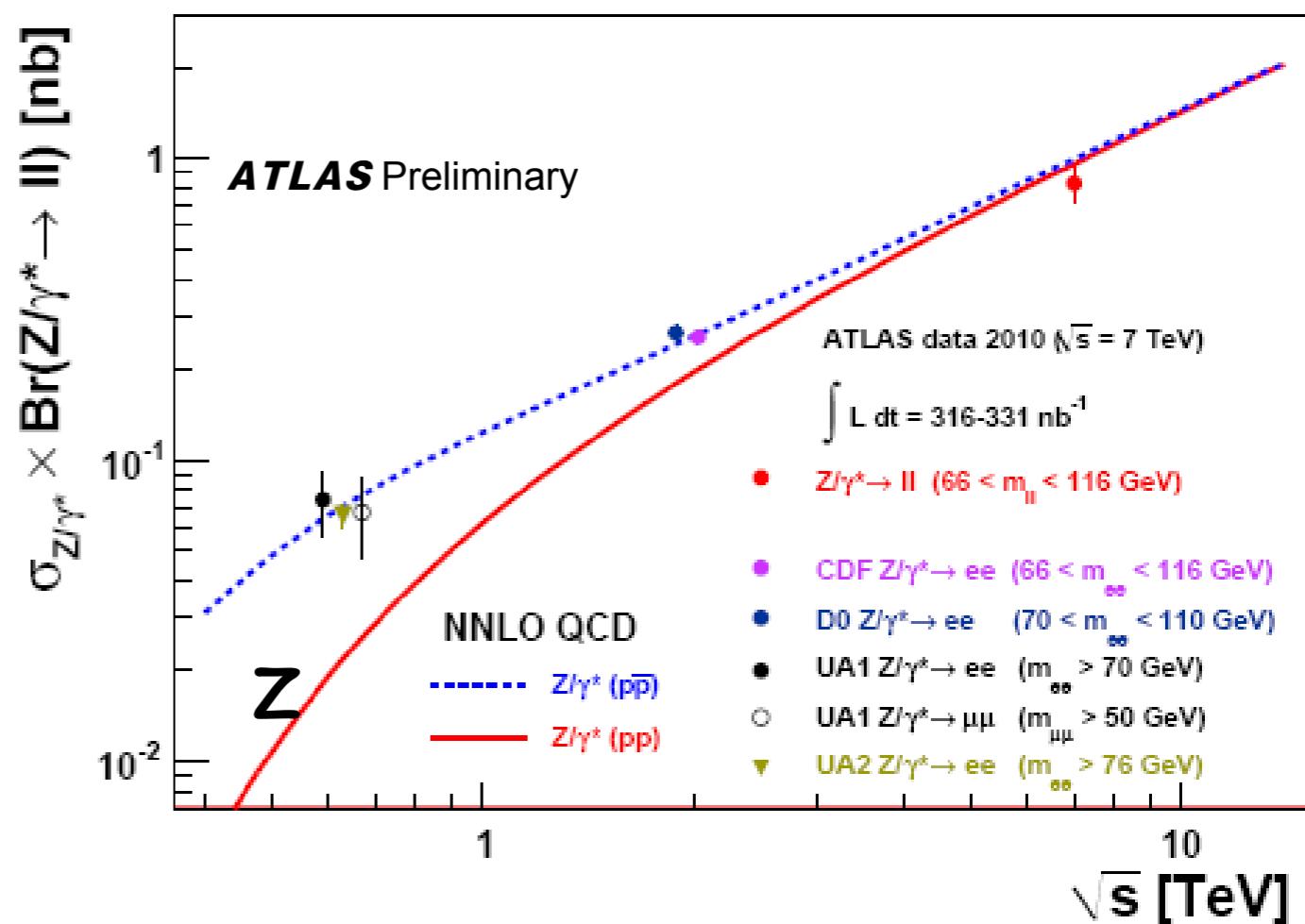
- Measured at $\sim 310/\text{nb}$
- $\sigma(W \rightarrow l\nu) = 9.96 \pm 0.23(\text{stat}) \pm 0.50(\text{syst}) \pm 1.10(\text{lumi}) \text{ nb}$
- $\sigma(W \rightarrow e\nu) = 10.51 \pm 0.34(\text{stat}) \pm 0.81(\text{syst}) \pm 1.16(\text{lumi}) \text{ nb}$
- $\sigma(W \rightarrow \mu\nu) = 9.58 \pm 0.30(\text{stat}) \pm 0.50(\text{syst}) \pm 1.05(\text{lumi}) \text{ nb}$
- $A = 0.20 \pm 0.02 \text{ (stat)} \pm 0.01 \text{ (syst)}$
- NNLO: $\sigma(W \rightarrow l\nu) = 10.46 \pm 0.52 \text{ nb}$
- Soon to constrain PDFs
- Dominant experimental uncertainties:
 - e : identification efficiency
 - μ : trigger + reconstruction efficiency



Z x-section

- Measured $\sim 315/\text{nb}$

- $\sigma(Z \rightarrow ll) = 0.82 \pm 0.06 \text{ (stat)} \pm 0.05 \text{ (syst)} \pm 0.09 \text{ (lumi)} \text{ nb}$
- $\sigma(Z \rightarrow ee) = 0.75 \pm 0.09 \text{ (stat)} \pm 0.08 \text{ (syst)} \pm 0.08 \text{ (lumi)} \text{ nb}$
- $\sigma(Z \rightarrow \mu\mu) = 0.87 \pm 0.08 \text{ (stat)} \pm 0.07 \text{ (syst)} \pm 0.10 \text{ (lumi)} \text{ nb}$
- NNLO: $(Z \rightarrow ll) = 0.96 \pm 0.05 \text{ nb}$
per family for $66 < M_{ll} < 116 \text{ GeV}$
- dominant experimental uncertainty: lepton reconstruction and identification
- Z+Jet x-section in progress.
 - $Z \rightarrow \mu\mu$ can be used to estimate $Z \rightarrow \nu\nu$ (though 6 times smaller)

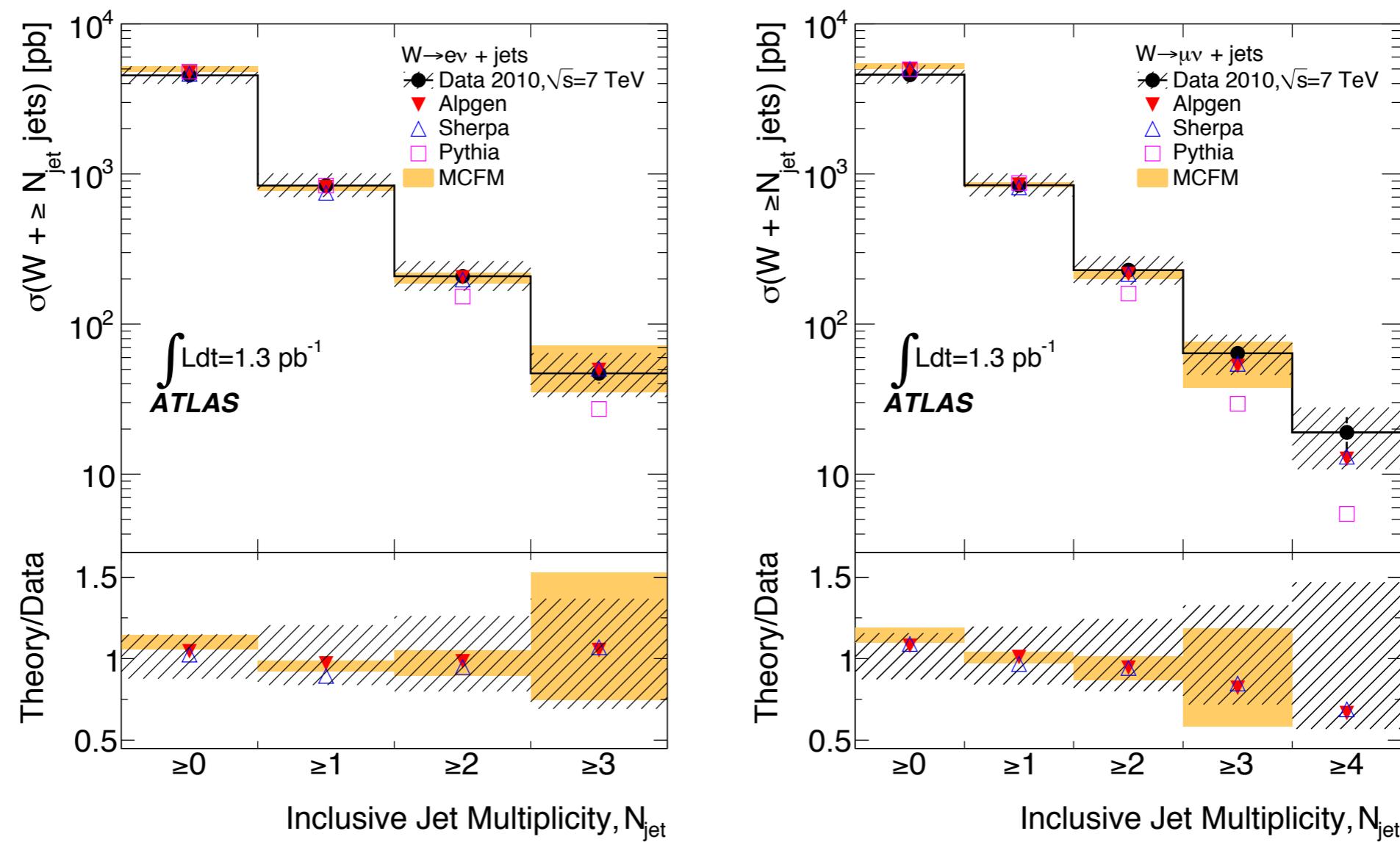


W+Jets x-section

1.3/pb
arXiv:1012.5382
submitted to Phys. Lett. B

Jet multiplicity	$W \rightarrow e\nu$ (nb)	MCFM $W \rightarrow e\nu$ (nb)	$W \rightarrow \mu\nu$ (nb)	MCFM $W \rightarrow \mu\nu$ (nb)
≥ 0	$4.53 \pm 0.07^{+0.35}_{-0.30} {}^{+0.58}_{-0.47}$	$5.08^{+0.11}_{-0.30}$	$4.58 \pm 0.07^{+0.38}_{-0.32} {}^{+0.61}_{-0.48}$	$5.27^{+0.11}_{-0.32}$
≥ 1	$0.84 \pm 0.03^{+0.13}_{-0.10} {}^{+0.11}_{-0.09}$	$0.81^{+0.02}_{-0.04}$	$0.84 \pm 0.03^{+0.11}_{-0.09} {}^{+0.11}_{-0.09}$	$0.84^{+0.02}_{-0.04}$
≥ 2	$0.21 \pm 0.01^{+0.04}_{-0.03} {}^{+0.03}_{-0.02}$	$0.21^{+0.01}_{-0.02}$	$0.23 \pm 0.02^{+0.04}_{-0.03} {}^{+0.03}_{-0.02}$	$0.21^{+0.01}_{-0.02}$
≥ 3	$0.047 \pm 0.007^{+0.014}_{-0.011} {}^{+0.008}_{-0.006}$	0.05 ± 0.02	$0.064 \pm 0.008^{+0.016}_{-0.014} {}^{+0.010}_{-0.008}$	0.05 ± 0.02
≥ 4	-	-	$0.019 \pm 0.005 \pm 0.006^{+0.004}_{-0.003}$	-

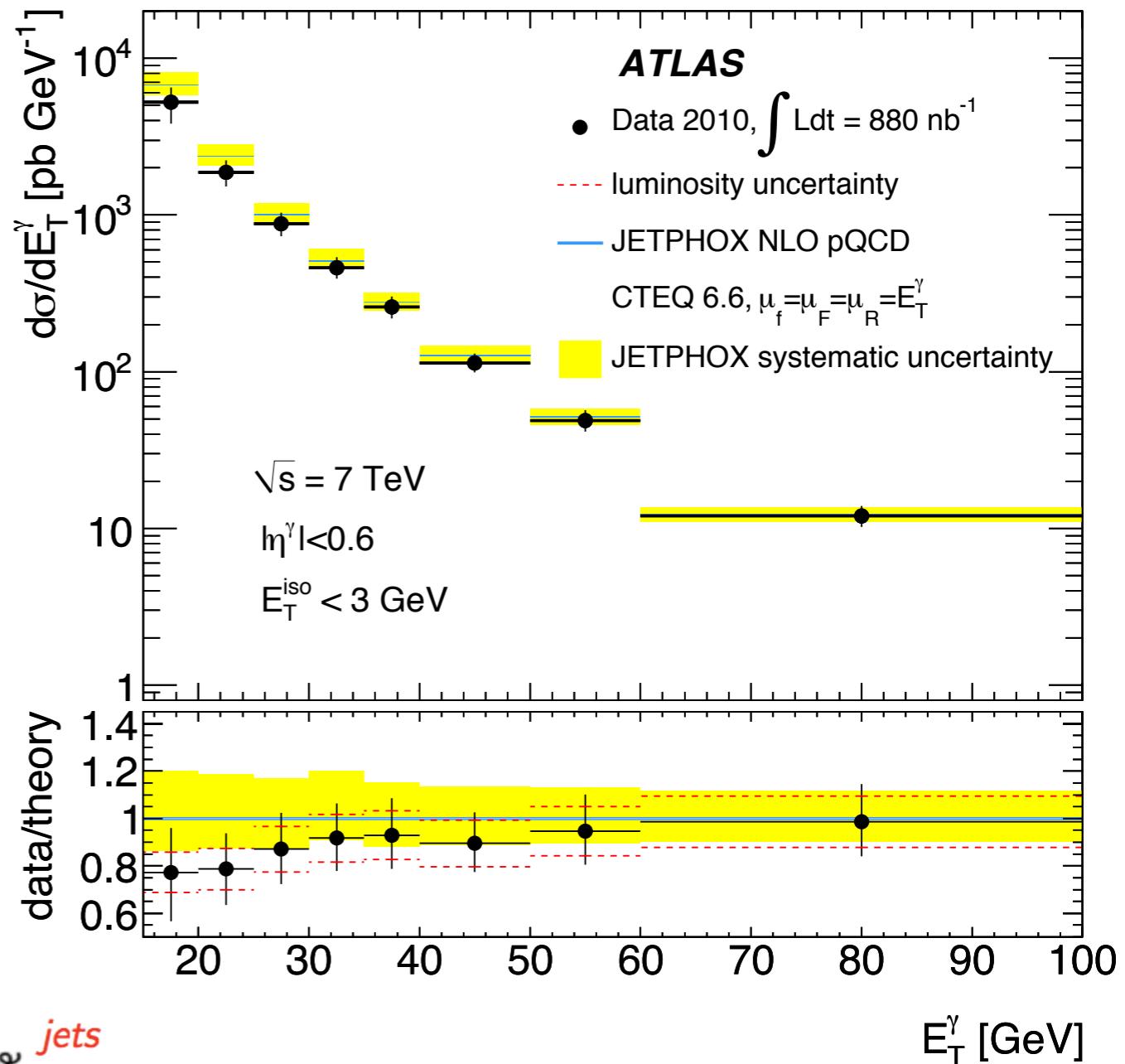
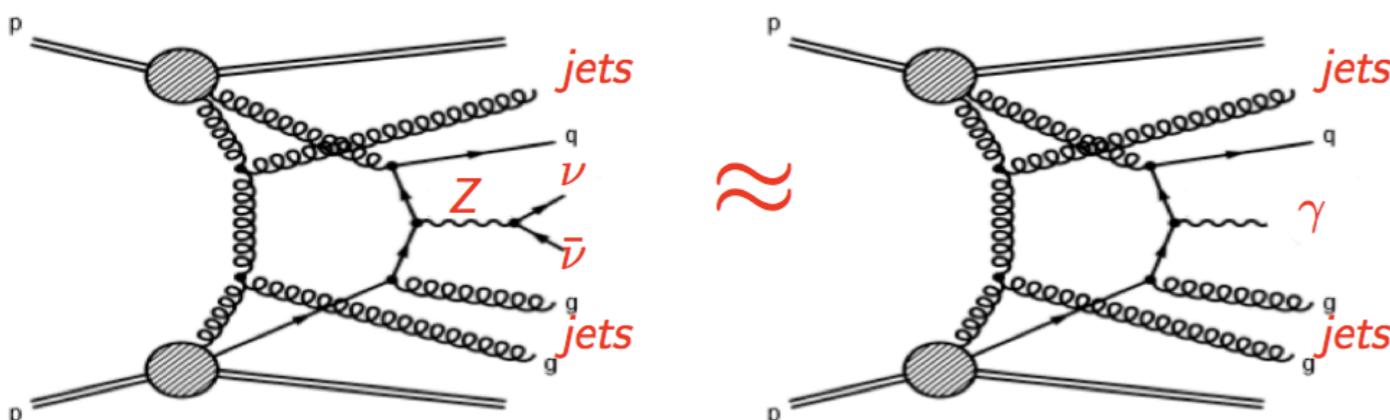
● Can also be used to estimate
 $Z \rightarrow VV$



Inclusive Direct Photon

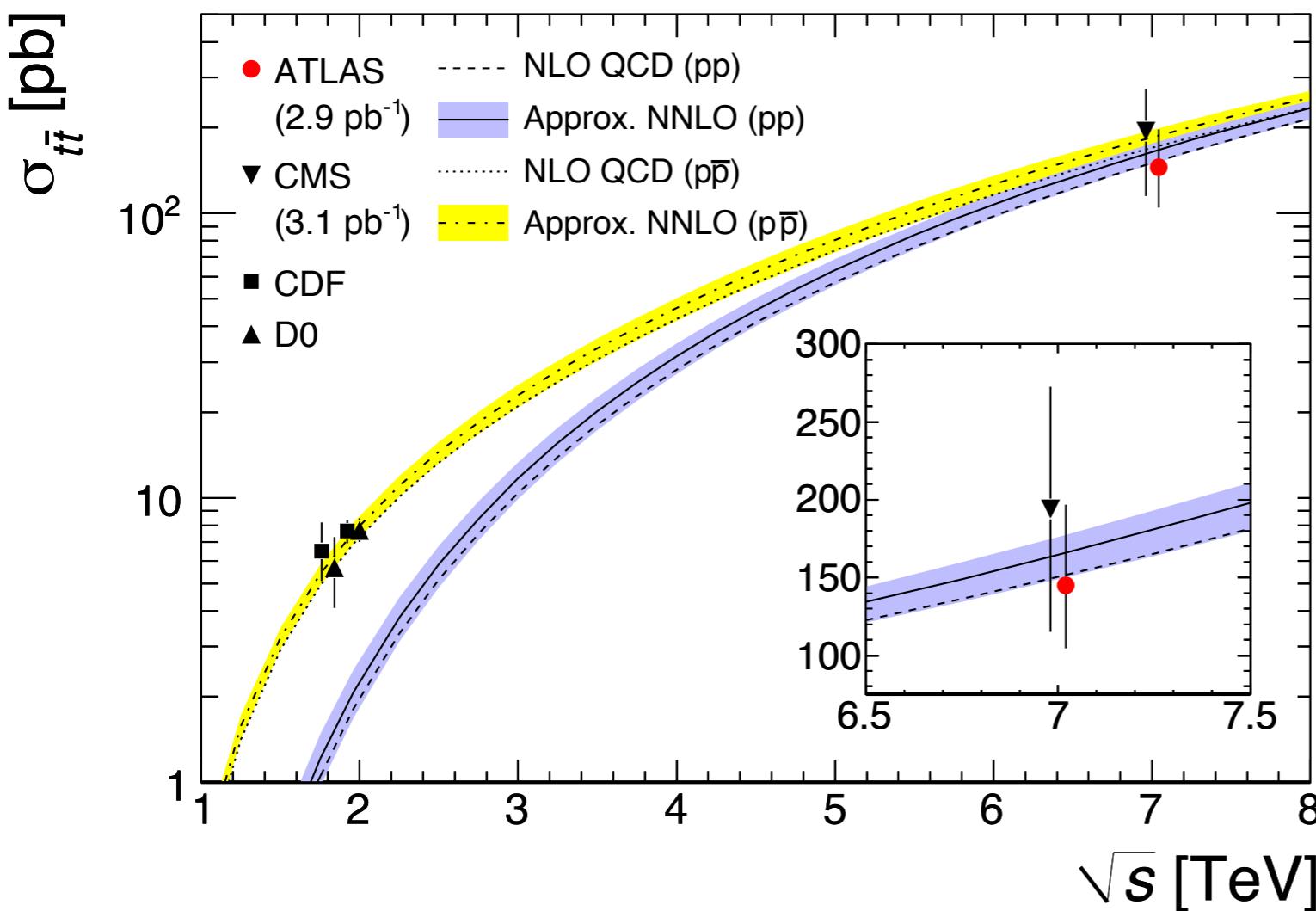
880/nb
arXiv:1012.4389
submitted to Phys. Rev. D

- Backgrounds to photon +MET
- γ +Jet and diphoton x-sections are next
- But γ +Jet is also interesting because it allows estimating $Z(\rightarrow \nu\nu) + \text{Jet}$.
- Higher statistics than $Z \rightarrow ll$ or W .



- The ratio $\frac{Z \rightarrow \nu\nu + \text{jets}}{\gamma + \text{jets}}$ stabilizes at high pT

Top



- Measured in lepton +Jet and dilepton.

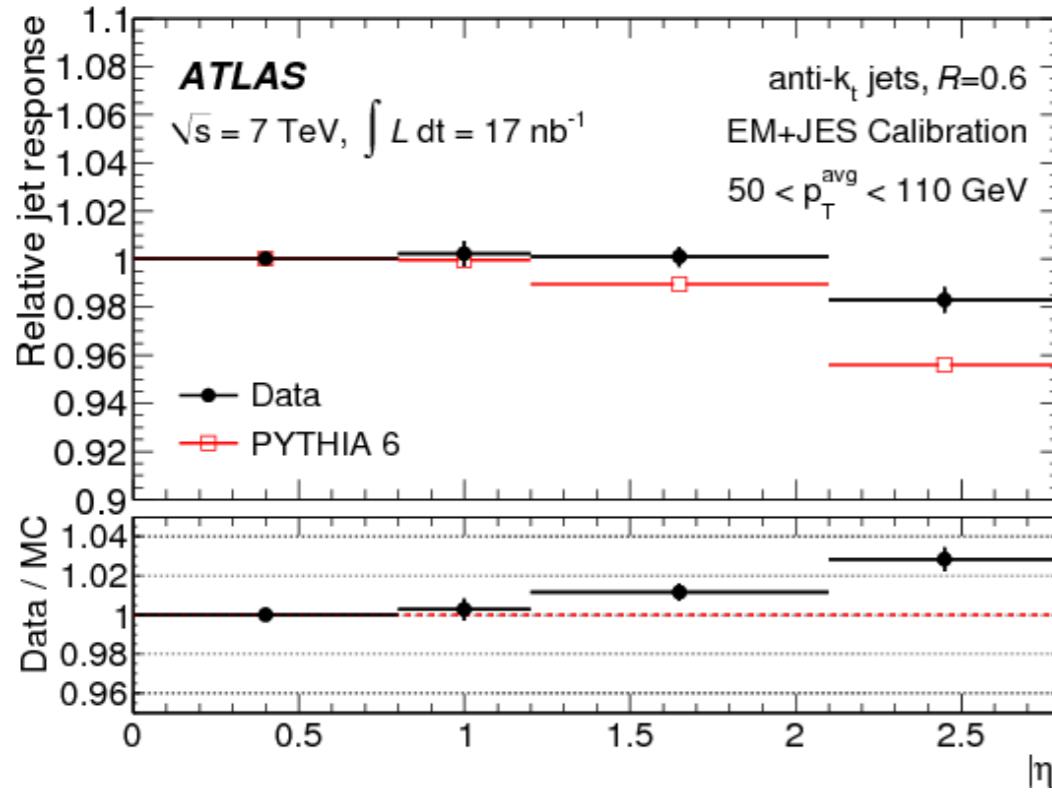
	Cross-section [pb]	Signal significance [σ]
Single lepton channels	$142 \pm 34^{+50}_{-31}$	4.0
Dilepton channels	151^{+78+37}_{-62-24}	2.8
All channels	$145 \pm 31^{+42}_{-27}$	4.8

SUSY in Data

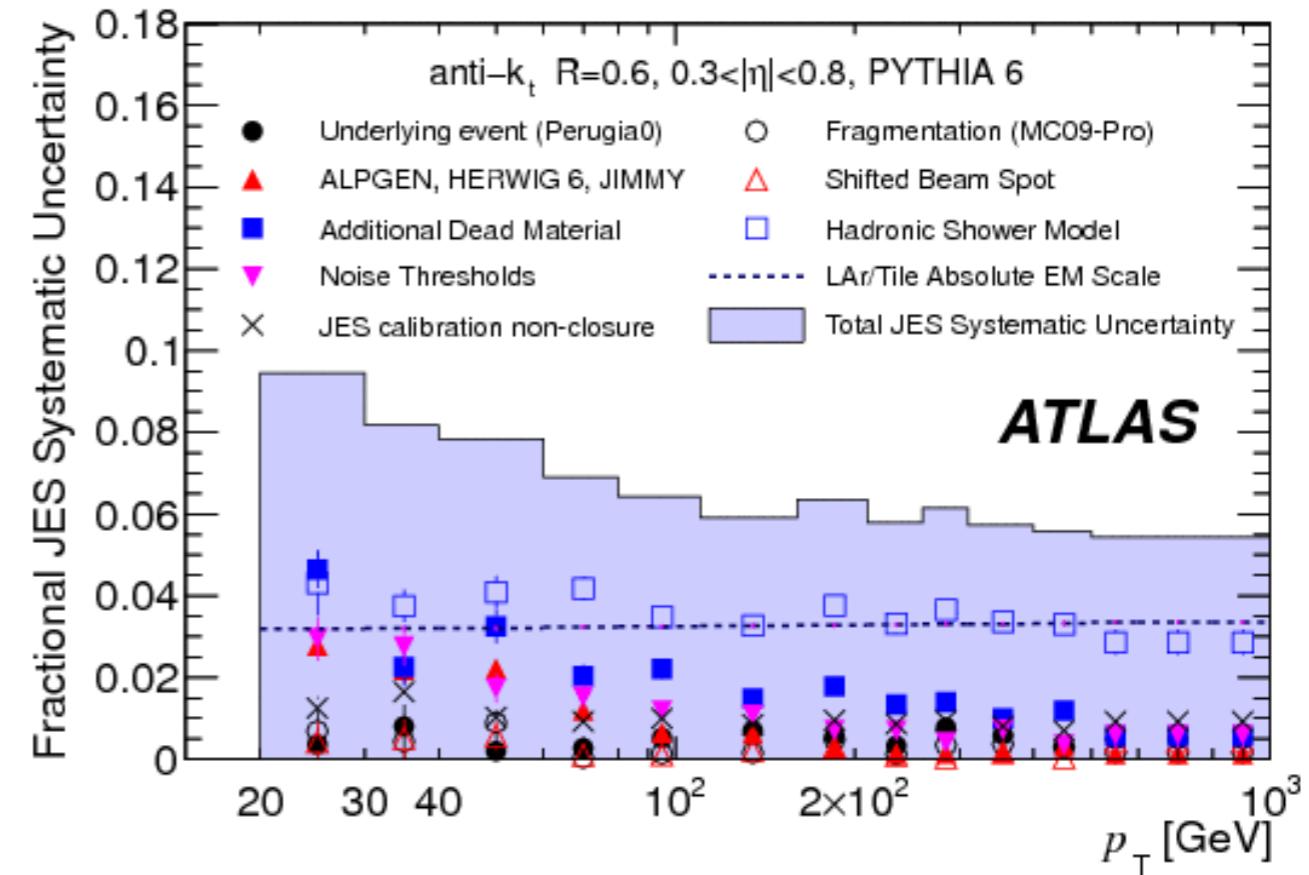
- Summer ~70/nb searches
 - Inputs: Jets, MET, [leptons]
 - Selections
 - Results

Jets

- *Jets built on “topological clusters”*
- *Corrected (in η/p_T bins)*
 - calorimeter non-compensation
 - dead material, etc.
- *Corrections Derived from MC*
 - tuned with “combined test-beam” data



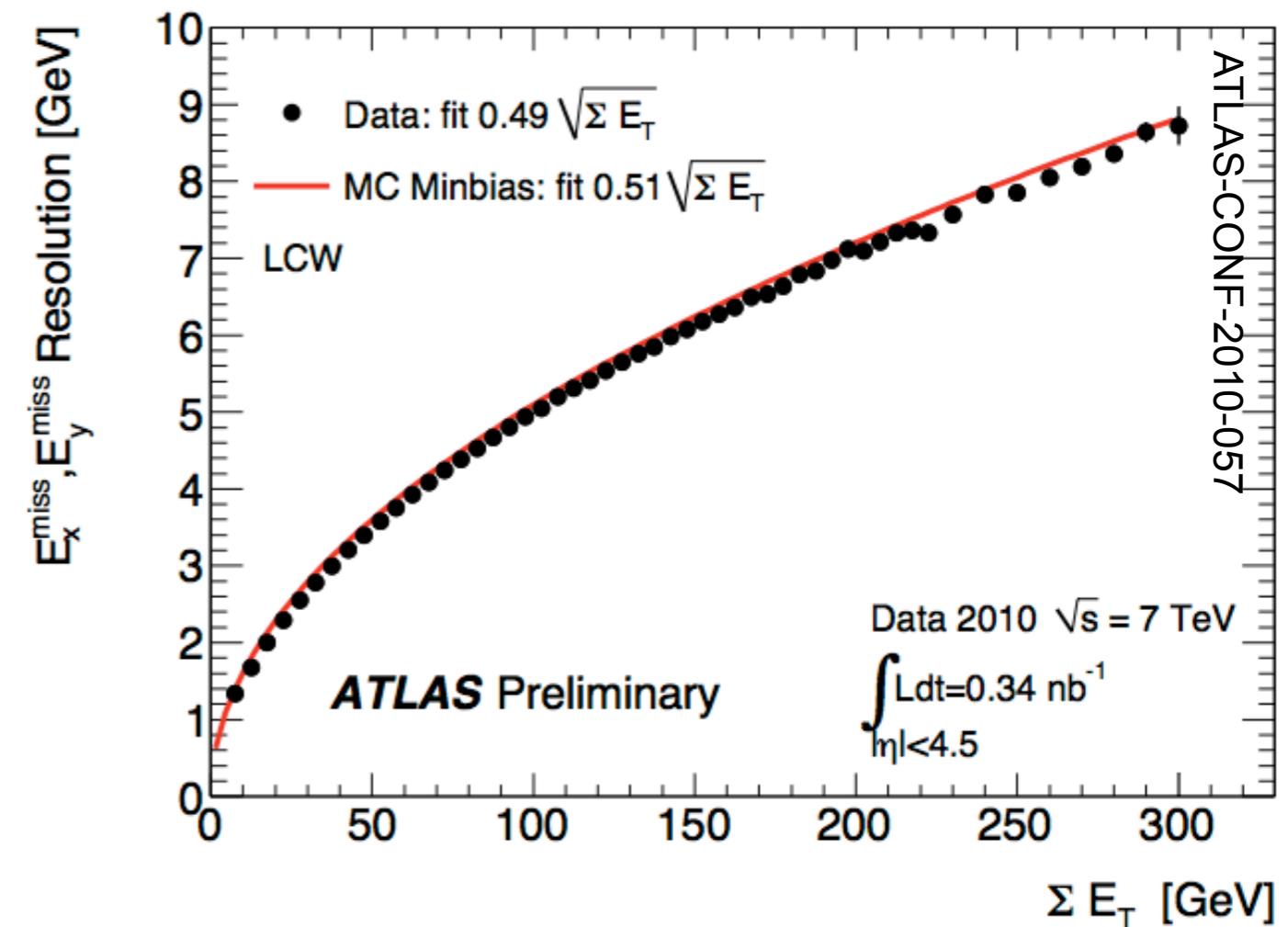
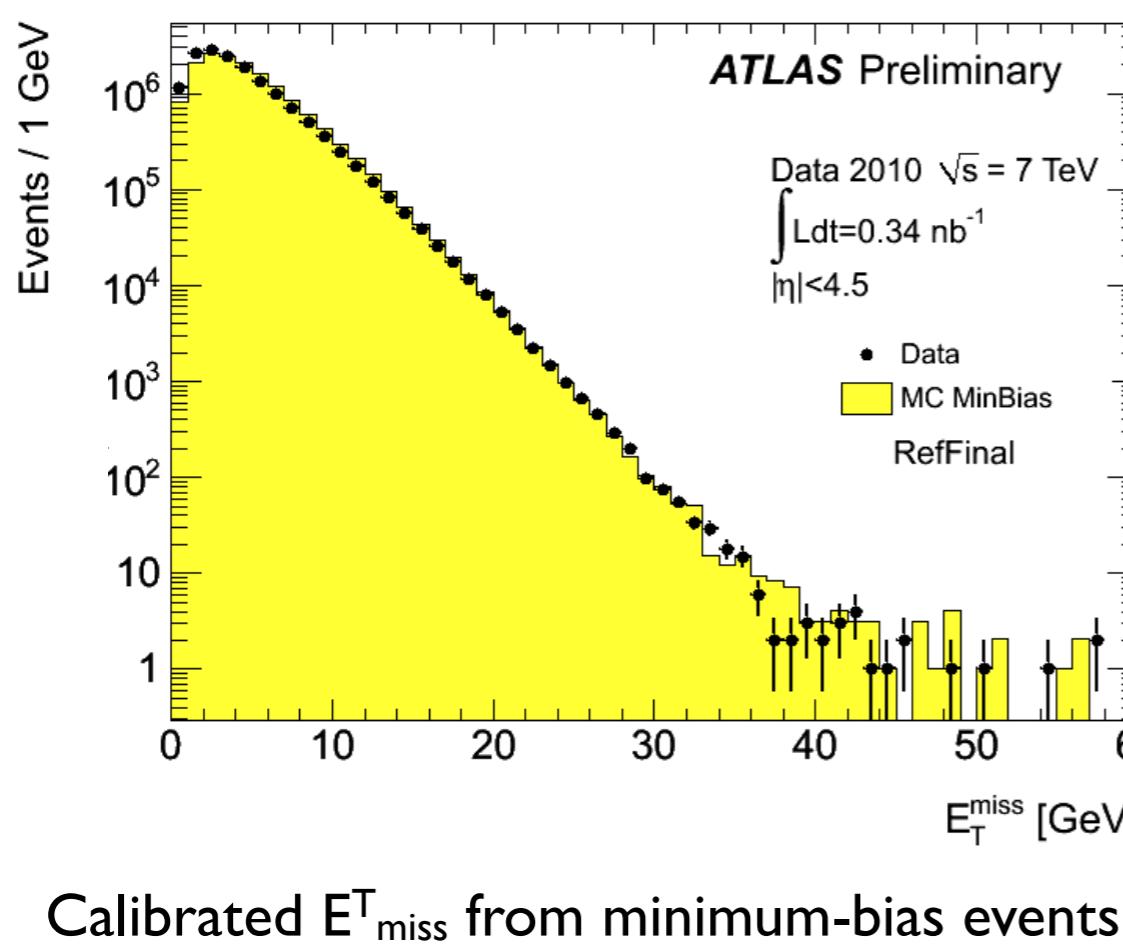
Central-forward inter-calibration checked using jet p_T -balance



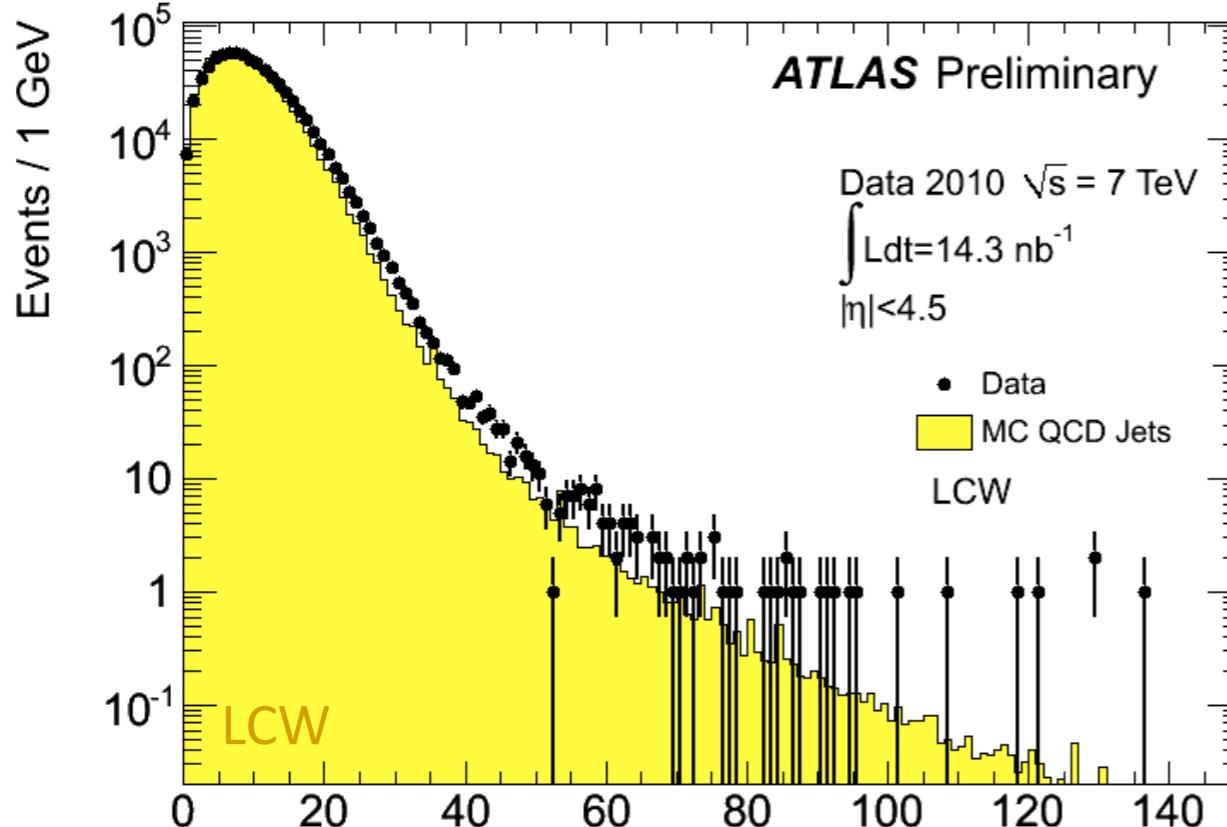
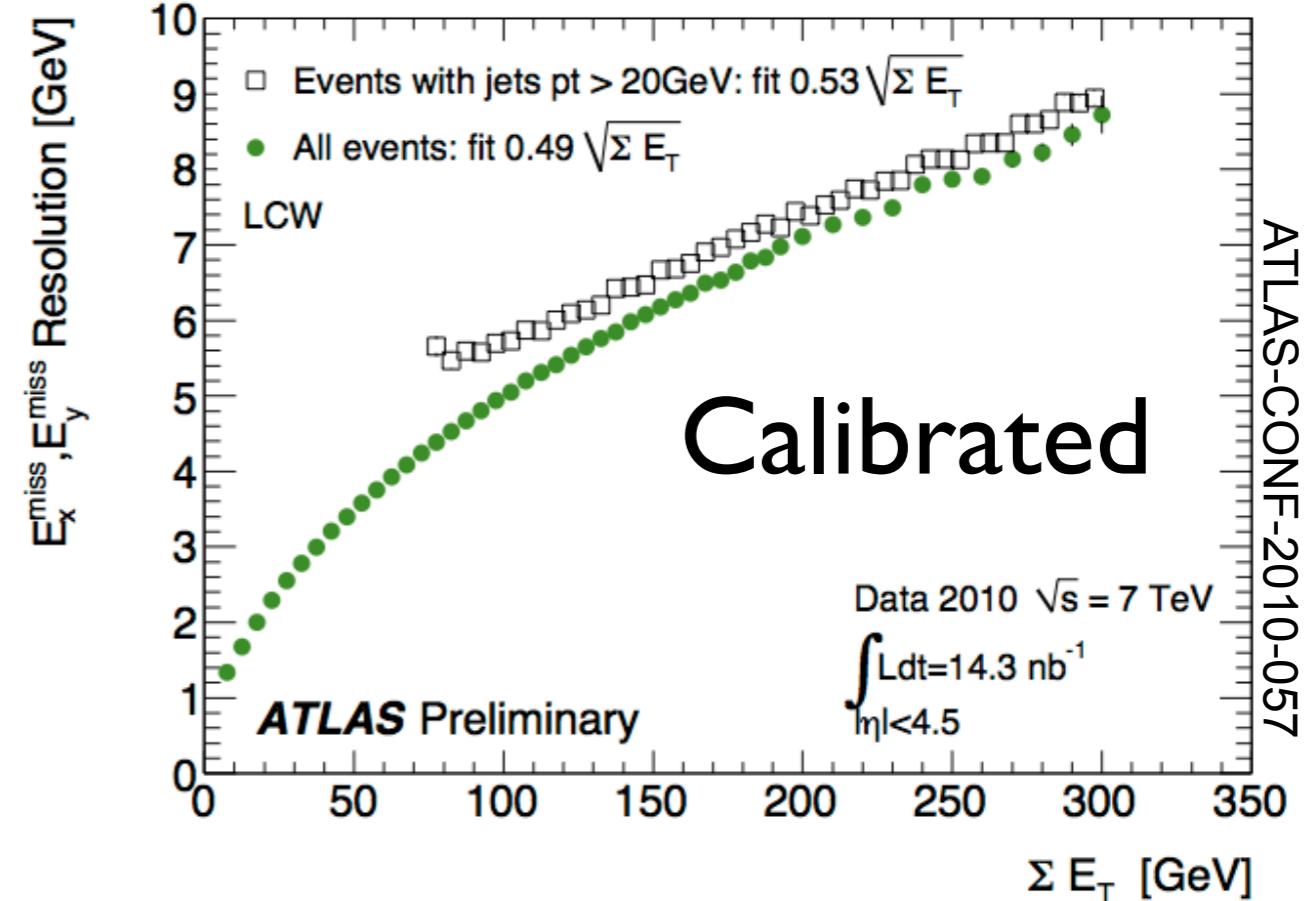
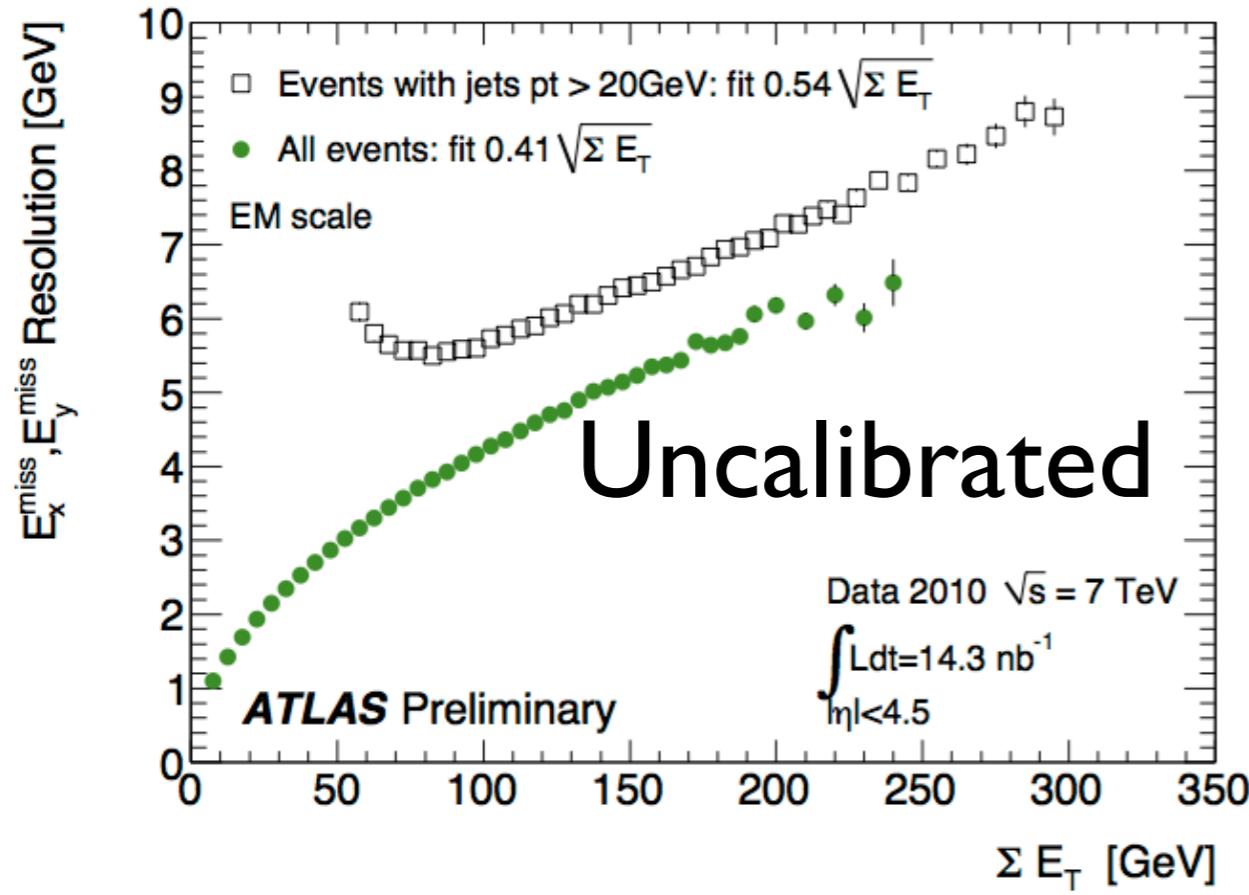
- *JES uncertainty $\sim 7\%$... goal 1%*
 - From Systematic Studies in MC
 - Checked in data:
 - Single particles
 - Dijet balance

MET

- *Calorimeter based + muons... objects identified/corrected*
- *Under control:*
 - *Calorimeter performance:* noise, coherent noise, dead cells, mis-calibrations, cracks, etc.
 - *Event cleaning:* Cosmics and beam-related backgrounds (“Event cleaning”)



MET with Jets



- Some data/MC disagreement in MET for events with high pT jets
 - But tails are generally under control
 - Smearing Jets in MC to reproduce Data Jet performance produces good Data/MC agreement in MET

Pre-Selections

0 lepton: Calo Trigger

- Good run/lumi block
- At least 1 vertex with at least 5 tracks
- **Jet Cleaning** (for noise, cosmics) (1% rejection).

Trigger	ϵ_{data}	ϵ_{MC}
L1_MU6 ($ \eta < 1.05$)	$73 \pm 5\%$	$80 \pm 3\%$
L1_MU6 ($1.05 < \eta < 2.4$)	$82 \pm 4\%$	$93 \pm 3\%$
EF_g10_loose	$81 \pm 5\%$	$85 \pm 5\%$

- Reject events with any bad Jets (for MET)
- Anti-Kt R=0.4 Topo Cluster **Jets** ($|\eta| < 2.5, p_T > 20 \text{ GeV}$)
 - Overlap Removal
- Medium (based on shower shape, pixel hit, d0) Isolated (etcone20 < 10GeV) **Electrons** ($|\eta| < 2.47, p_T > 10 \text{ GeV}$)
 - $R(\text{jet}, \text{electron}) < 0.2$
 - reject jet
 - $0.2 < R(\text{jet}, \text{electron}) < 0.4$
 - veto electron
- Combined Isolated (etcone20 < 10GeV) **Muons** ($|\eta| < 2.4, p_T > 10 \text{ GeV}$)
 - $R(\text{jet}, \muon) < 0.4$
 - veto muon
- **MET** calculated from em-scale Topo-clusters and selected muons

Event Selections

- 0 Lepton
- No leptons > 10 GeV

$$M_{\text{eff}} = \sum p_T + \text{MET}$$

Number of jets	Monojets	≥ 2 jets	≥ 3 jets	≥ 4 jets
Leading jet p_T (GeV)	> 70	> 70	> 70	> 70
Subsequent jets p_T (GeV)	veto if > 30	> 30	> 30 (Jets 2 and 3)	> 30 (Jets 2 to 4)
E_T^{miss}	> 40 GeV	> 40 GeV	> 40 GeV	> 40 GeV
$\Delta\phi(\text{jet}_i, \vec{E}_T^{\text{miss}})$	no cut	[$> 0.2, > 0.2$]	[$> 0.2, > 0.2, > 0.2$]	[$> 0.2, > 0.2, > 0.2, > 0$]
$E_T^{\text{miss}} > f \times M_{\text{eff}}$	no cut	$f = 0.3$	$f = 0.25$	$f = 0.2$

- 1/2 Lepton
 - 2 Jets > 30 GeV
 - Exactly 1 or 2 lepton(s) > 10 GeV \rightarrow 1/2 lepton
 - Require: 1 lepton > 20 GeV

QCD Background Estimation

- 0 lepton:
 - The selected 2 jets sample is expected to be dominated by QCD.
 - 176000 PYTHIA vs 108239 in Data
 - absolute PYTHIA to data normalization factor = 0.61
 - given our data stats, shape of distributions agree between PYTHIA and ALPGEN (n=2,3,4,5 parton)
 - Assume shape is well described by MC
- 1/2 lepton:
 - For each sample calculate “MC to data factor” in QCD dominated region:
 - $m_T < 40 \text{ GeV} / \text{MET} < 40 \text{ GeV}$
 - assign 100% systematic error
 - We now build QCD control regions by reversing the $\Delta\Phi(\text{jets}, \text{MET})$ cut

	Data	Monte Carlo	Normalization factor
Electron channel	101	245	0.41 ± 0.08
Muon channel	15	31.4	0.48 ± 0.12

Channel	Data	Monte Carlo	Data/Monte Carlo
$e e$	3	6.3 ± 3.5	0.4 ± 0.4
$e \mu$	1	1.0 ± 0.4	1.0 ± 1.0
$\mu \mu$	3	0.6 ± 0.3	4.9 ± 3.7

W+Jet Backgrounds

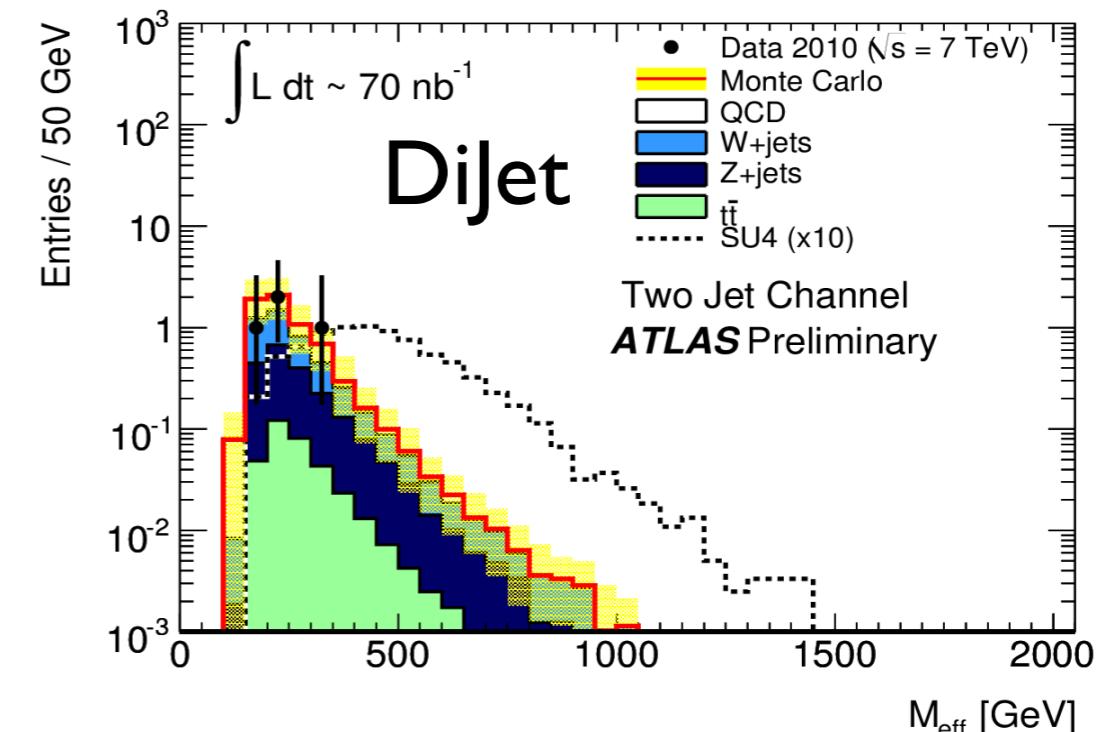
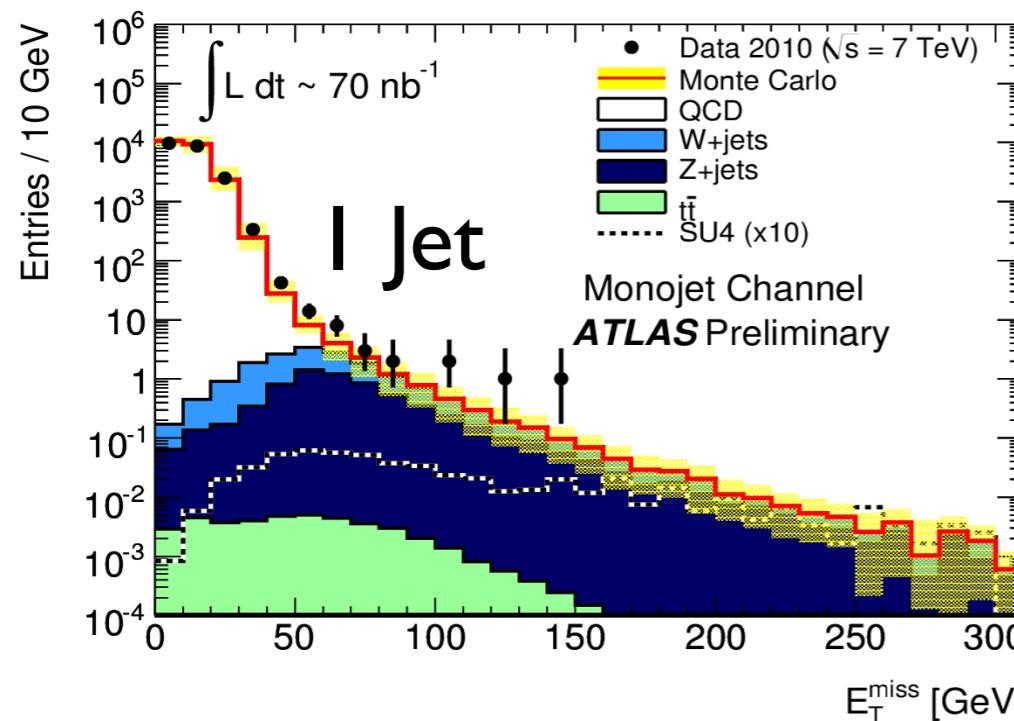
- 0 Lepton (use MC due to low stats at the time)
 - W/Z+Jets: Alpgen (W/Z+n parton) + Herwig + Jimmy + CTEQ6LI. FEWZ for NNLO x-section (for final-states with neutrinos)
 - tt: MC@NLO + HERWIG + JIMMY + CTEQ6.6
- 1/2 Lepton
 - W + n Jets ($n > 1$):
 - normalize to $30 < \text{MET} < 50 \text{ GeV} / 40 < M_T < 80 \text{ GeV}$ region.
 - assign 50% systematic for extrapolation to signal region

Channel	Observed	W expectation	Other SM expectation
Electron	6	2.2	0.8
Muon	4	2.1	0.3

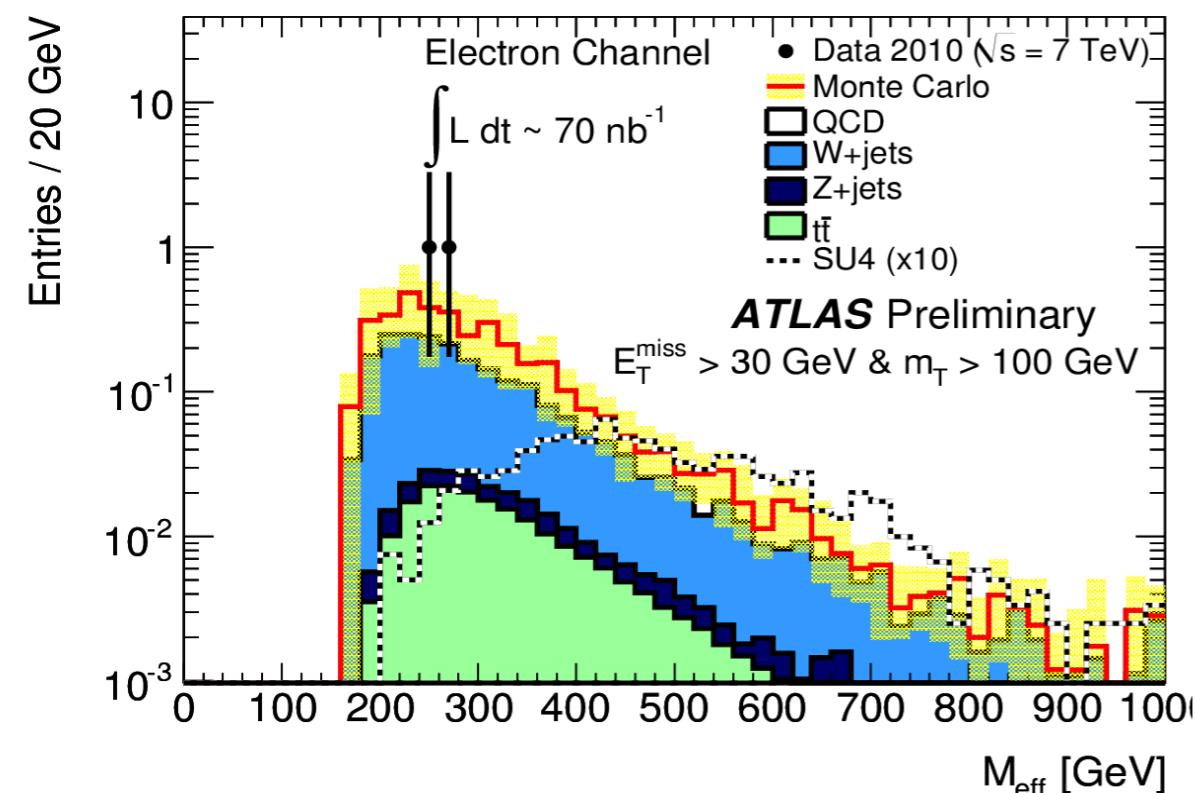
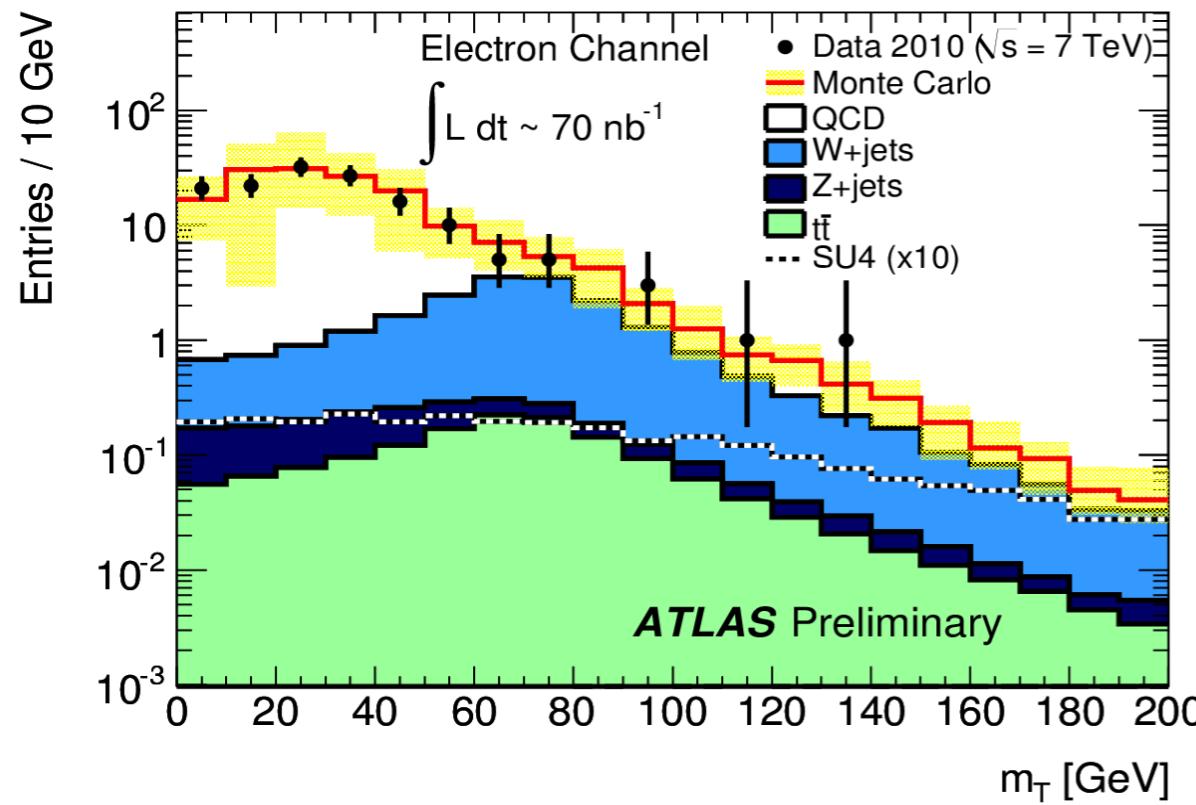
Results

- No limits calculated by ATLAS... just raw yields and plots
 - See Jay Wacker's talk on their interpretation of our results
- No deviations from SM observed

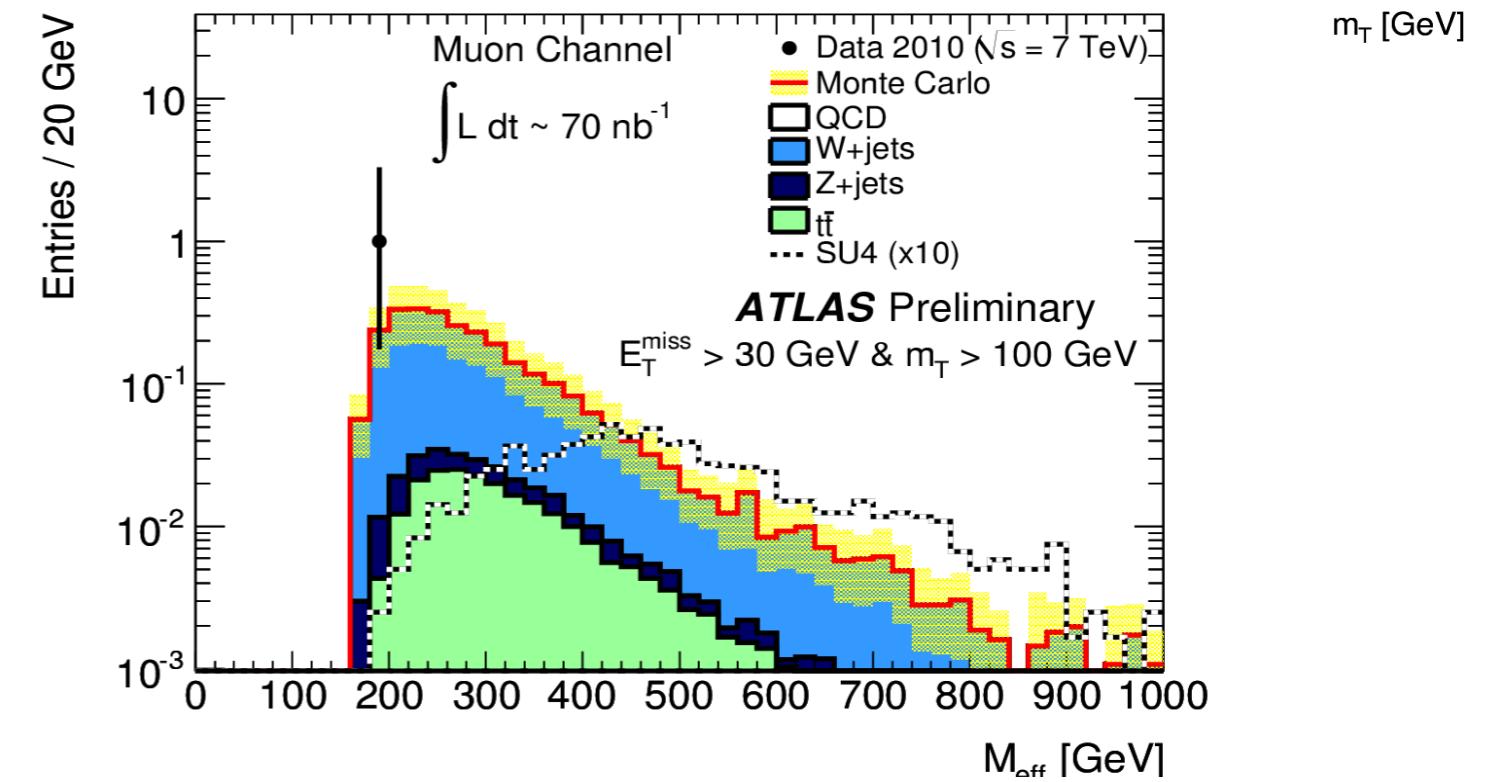
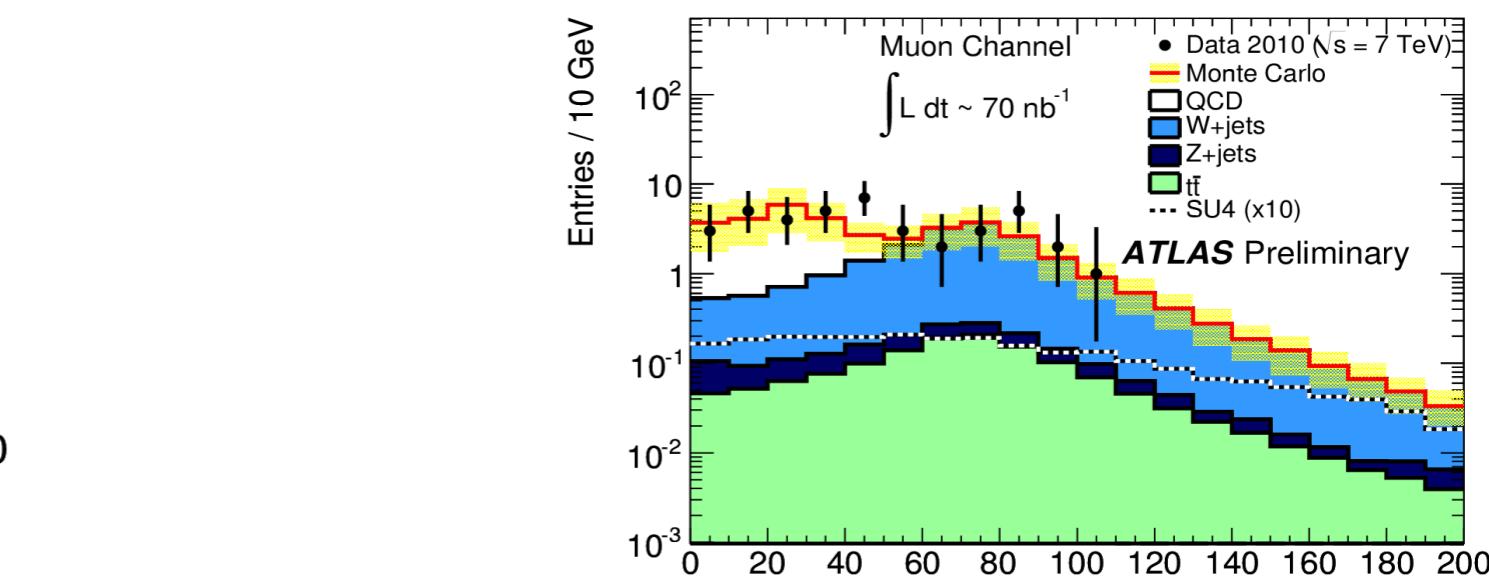
	Monojet		≥ 2 jets		≥ 3 jets		≥ 4 jets	
	Data	Monte Carlo	Data	Monte Carlo	Data	Monte Carlo	Data	Monte Carlo
After jet cuts	21227	23000^{+7000}_{-6000}	108239	108000^{+31000}_{-25000}	28697	31000^{+10000}_{-8000}	5329	5600^{+2300}_{-1600}
$\cap E_T^{\text{miss}}$ cut	73	46^{+22}_{-14}	650	450^{+190}_{-120}	325	230^{+100}_{-70}	116	84^{+45}_{-30}
$\cap \Delta\phi$ and E_T^{miss} cuts	–	–	280	200^{+110}_{-65}	136	100^{+55}_{-30}	54	43^{+26}_{-16}
$\cap E_T^{\text{miss}}/M_{\text{eff}}$, $\Delta\phi$ and E_T^{miss} cuts	–	–	4	6.6 ± 3	0	1.9 ± 0.9	1	1.0 ± 0.6



Results

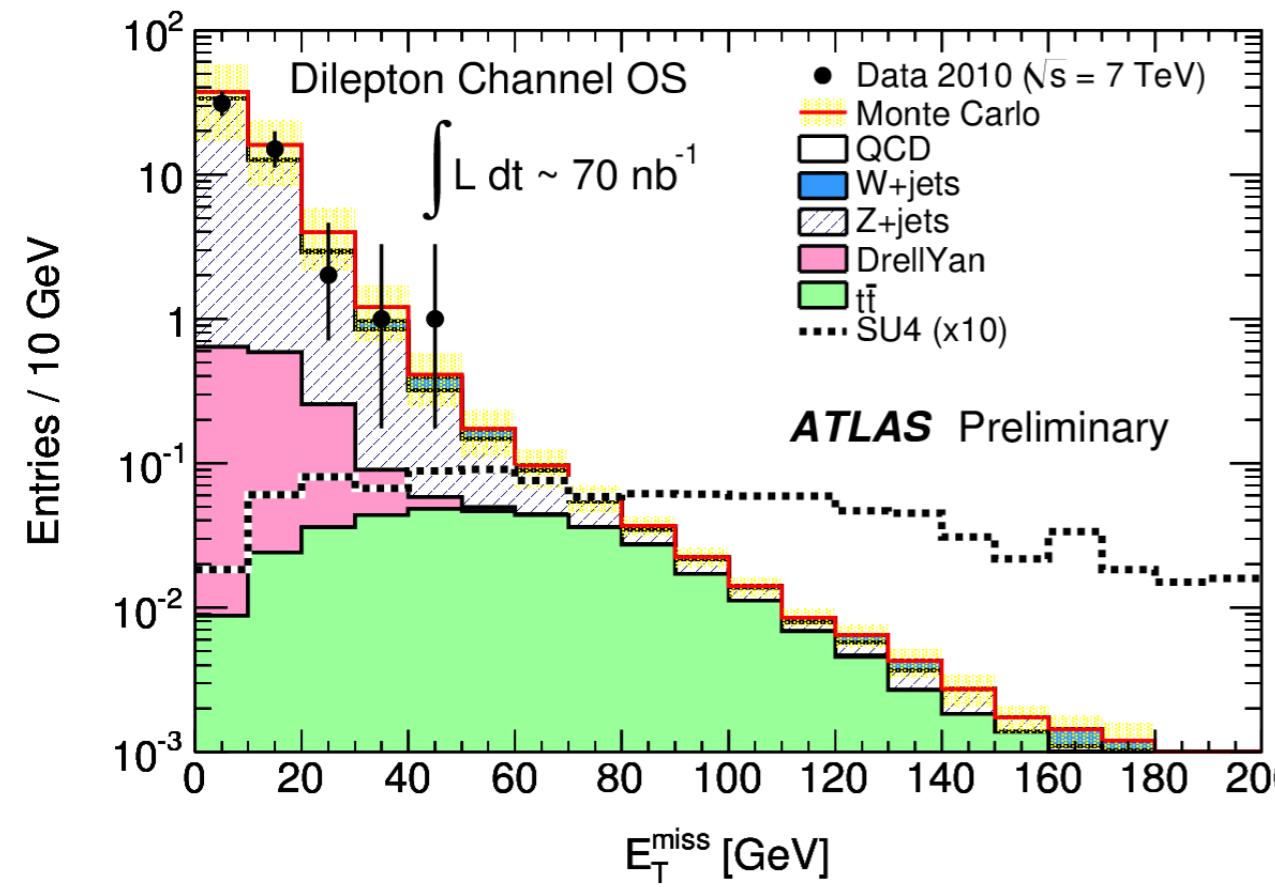


Selection	Electron channel		Muon channel	
	Data	Monte Carlo	Data	Monte Carlo
$p_T(\ell) > 20 \text{ GeV} \cap$ $\geq 2 \text{ jets with } p_T > 30 \text{ GeV}$	143	157 ± 85	40	37 ± 14
$\cap E_T^{\text{miss}} > 30 \text{ GeV}$	13	16 ± 7	17	15 ± 7
$\cap m_T > 100 \text{ GeV}$	2	3.6 ± 1.6	1	2.8 ± 1.2

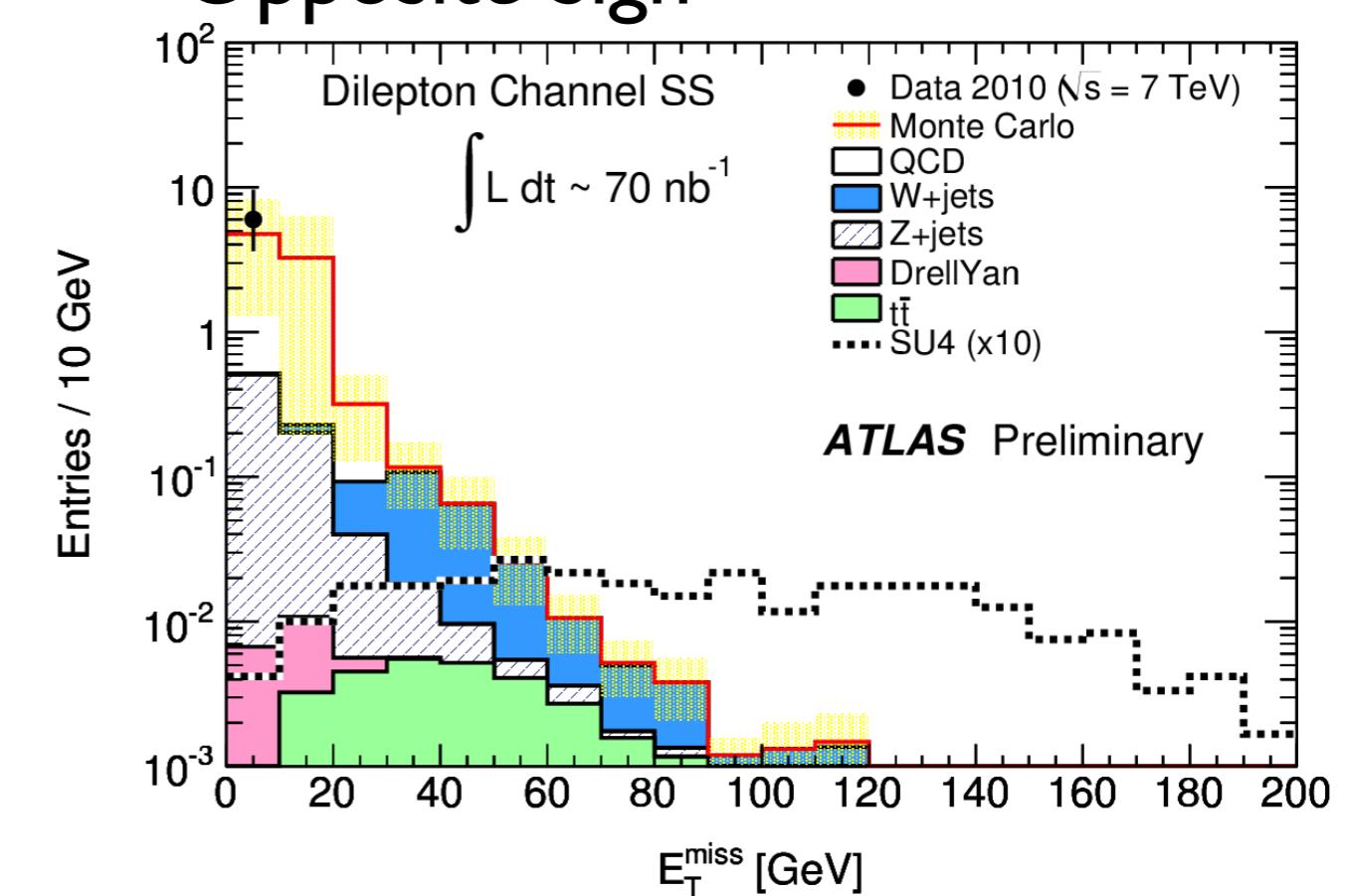


Results

Same Sign



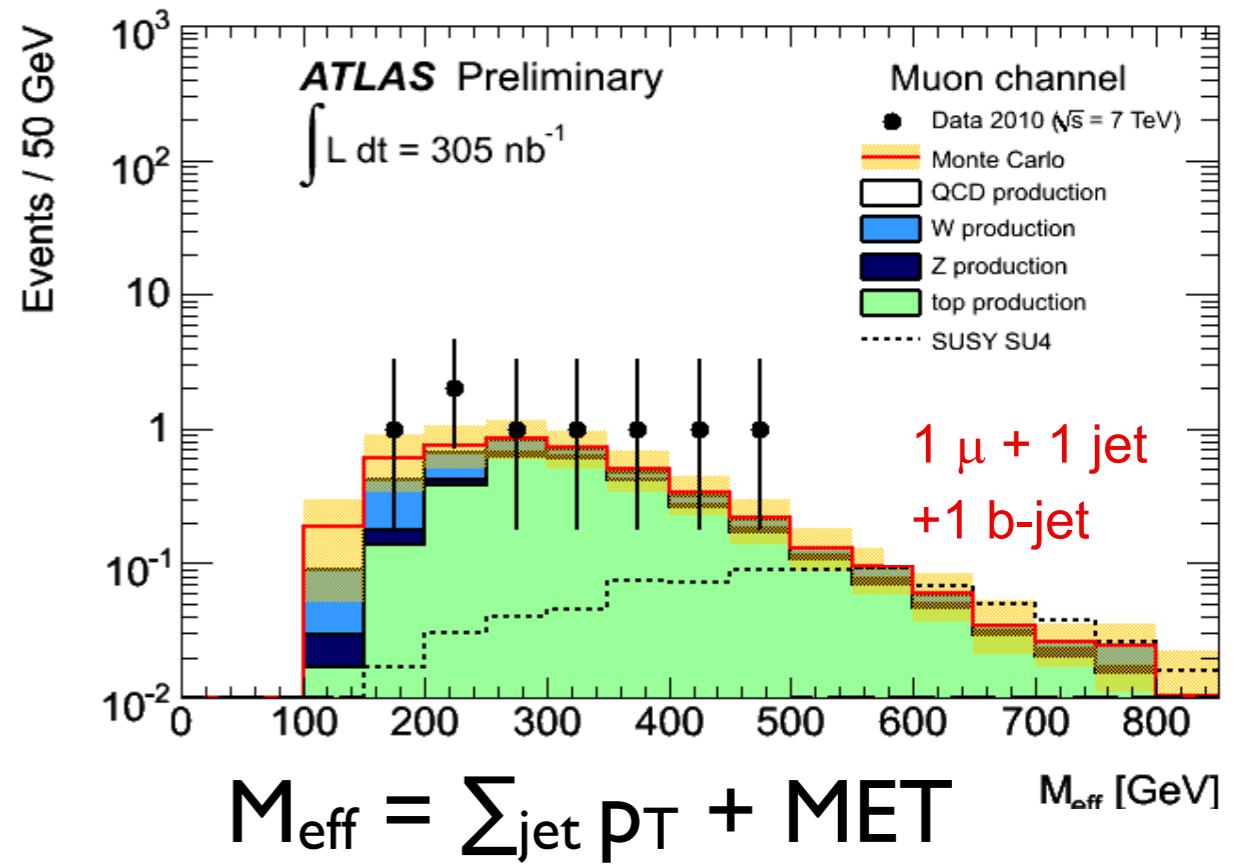
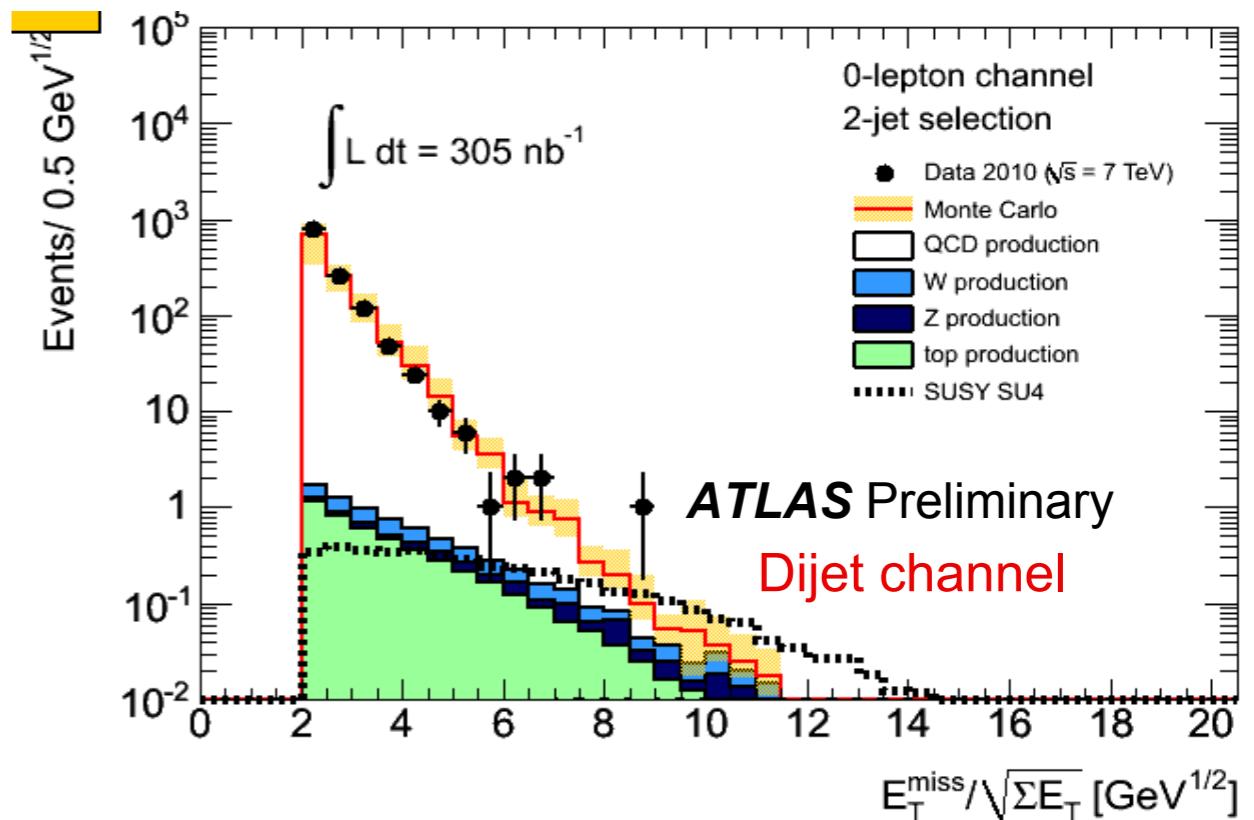
Opposite Sign



Results

ATLAS-CONF-2010-079

- High $\tan \beta$
- Secondary vertex b-tagging algorithm:
 - Decay length significance: $L/s > 6$
 - b-tagging $\sim 50\% \text{ Eff}$
 - Rejection $>98\%(\text{light}), >80\%(\text{charm})$
- Di-jet channel: “2-j (70,30)”, at least one b-jet
- lepton+jets channel
 - One isolated muon
 - $> 2\text{-jets (30,30)}$ at least one b-jet
 - $E_T^{\text{miss}}/\sqrt{\sum E_T} > 2 \text{ GeV}$

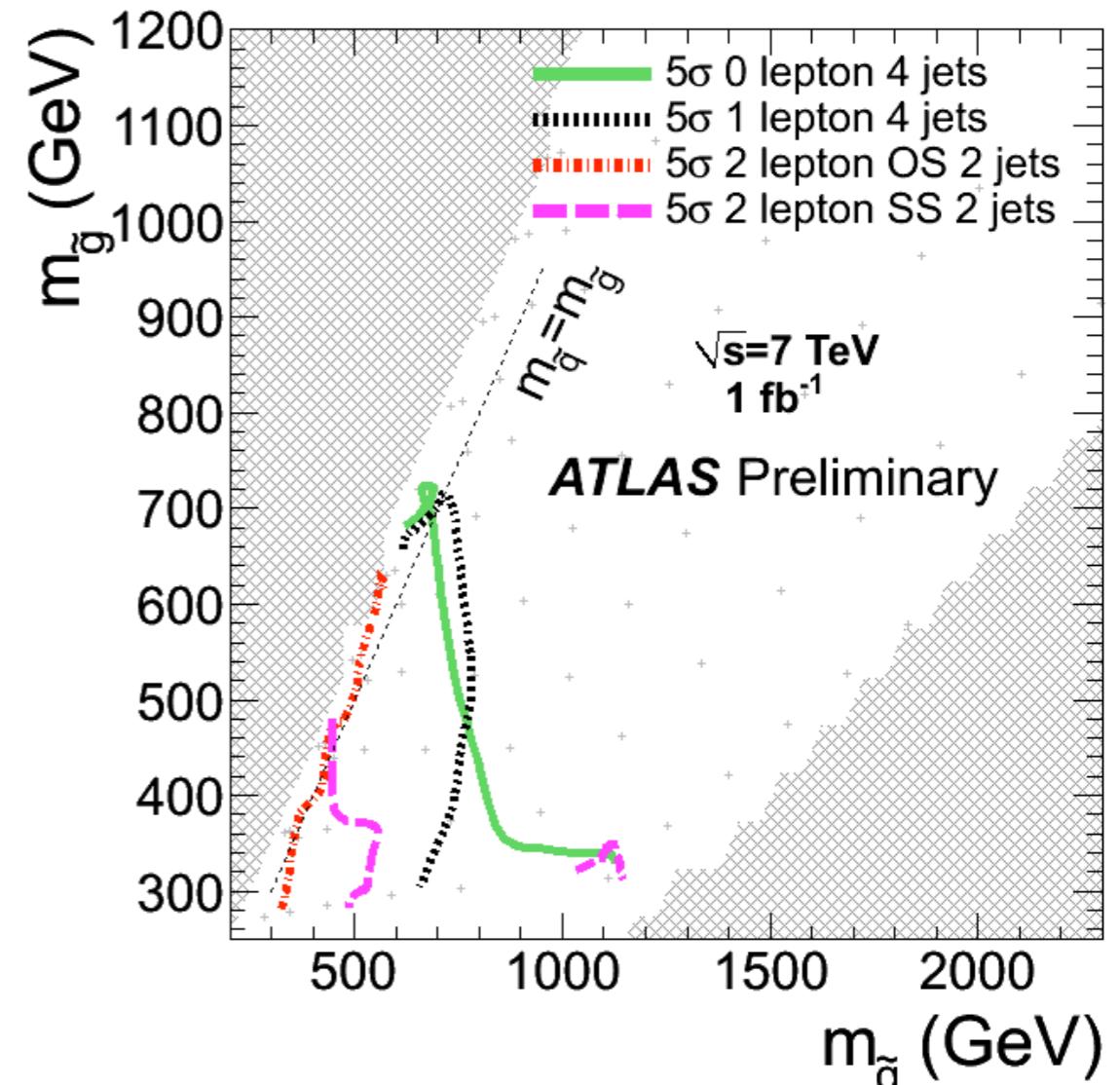
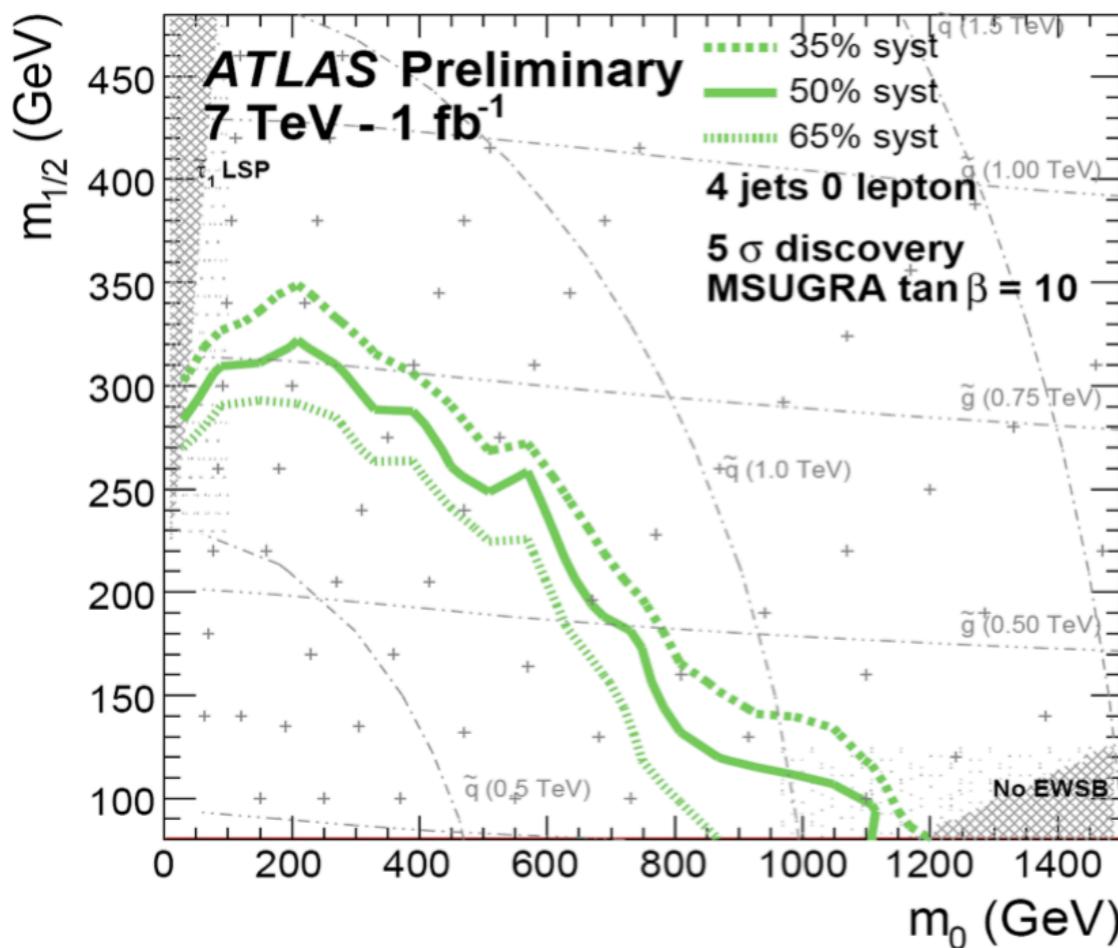


SUSY Prospects

MC

ATLAS-PHYS-PUB-2010-010

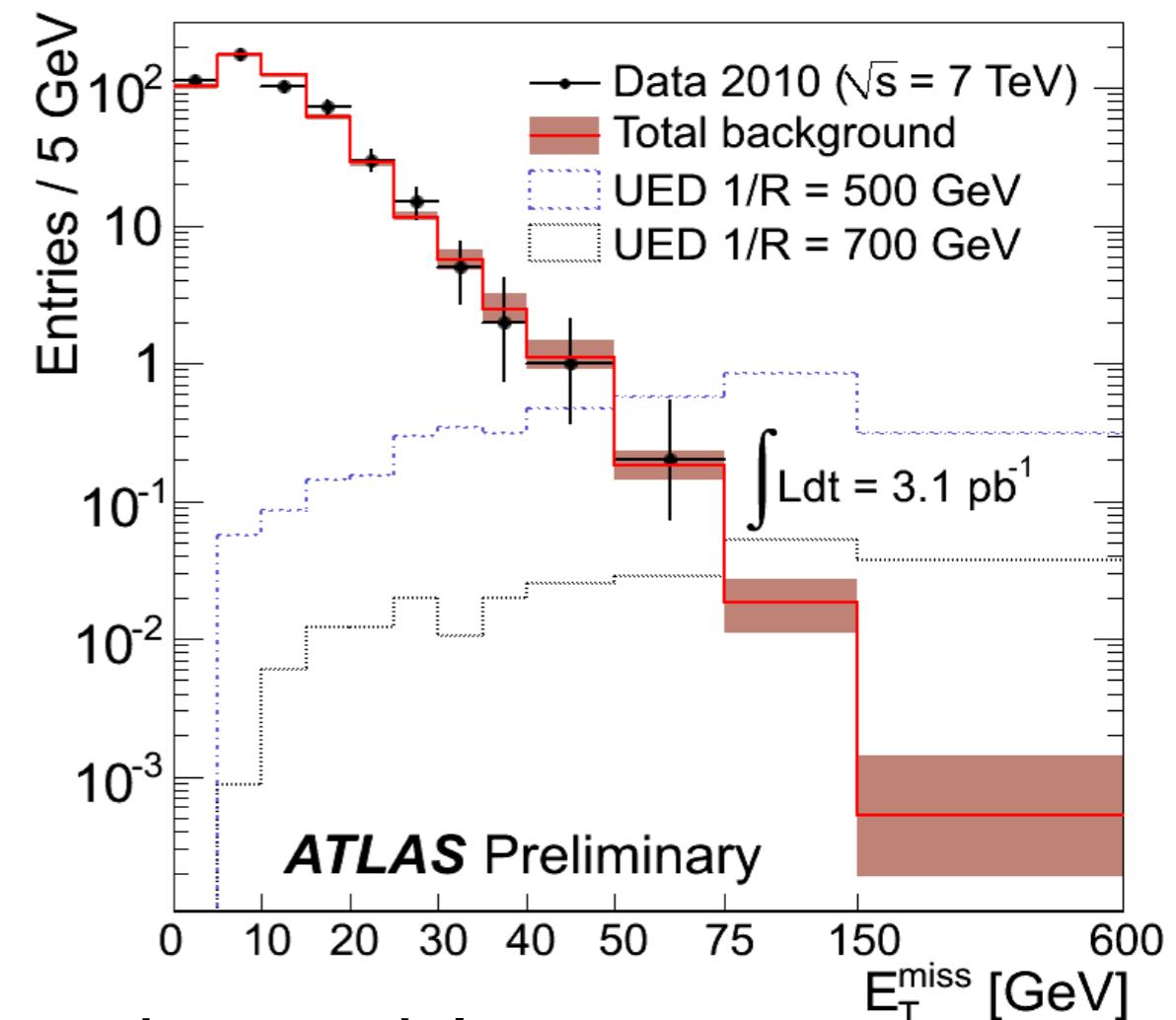
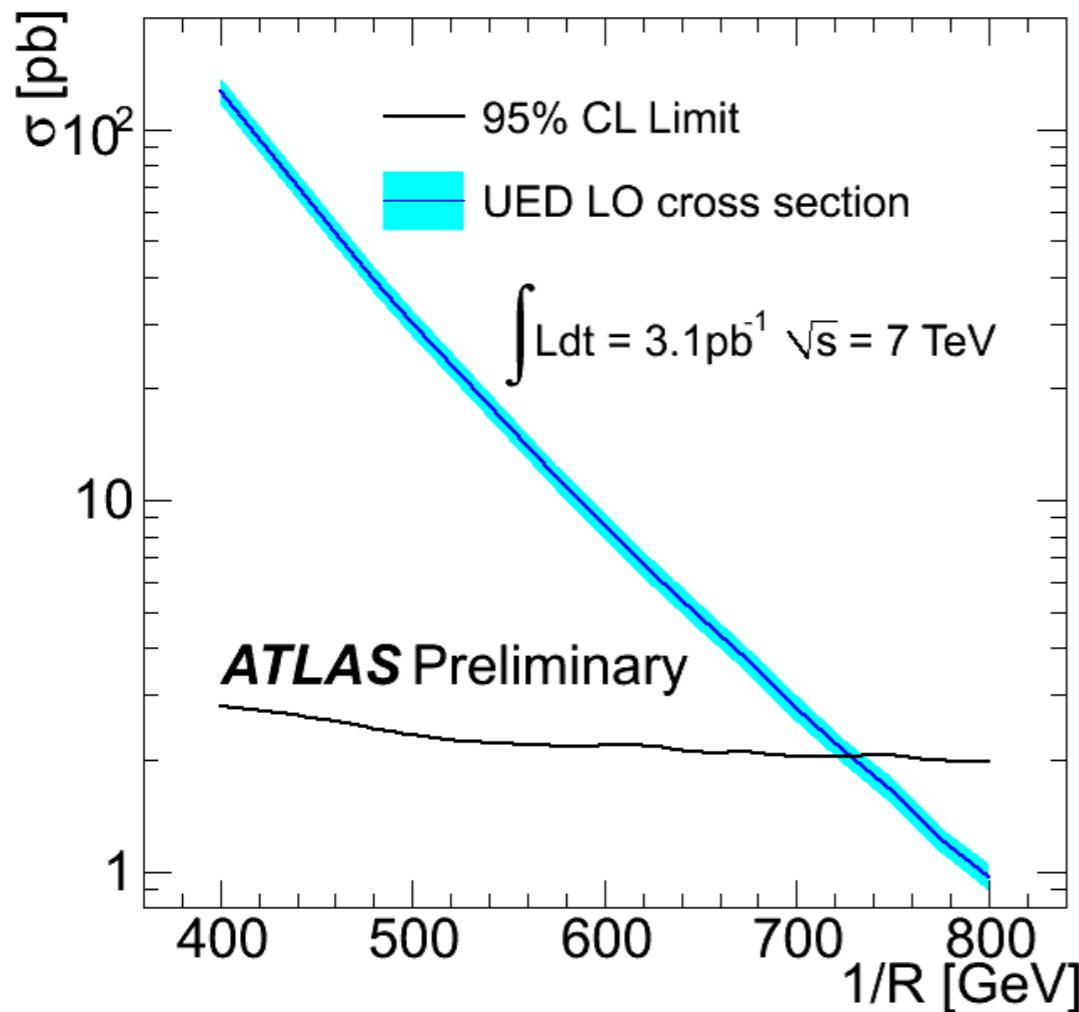
- Best reach in 0 lepton + 4 Jets + MET
- All Hadronic channels present a Trigger challenge



- mSUGRA Discovery reach with 50% bkg systematic
- squarks/gluinos up to 700 GeV
- exclusion beyond Tevatron at 10/pb.

Diphoton+MET

- Look for 2 photons w/ $E_T > 25 \text{ GeV}$ and $E_{\text{Had}}/E_T < 0.2$
- UED signal expected at $\text{MET} > 75$
 - keep expected bkg to 1



- Fix other model parameters ($\Lambda R = 20, N = 6, M_D = 5 \text{ TeV}$)... put limit on $1/R > 728 \text{ GeV}$
 - D0 limit is at 477 GeV
 - No GMSB limit calculated (not competitive with 3.1/pb)

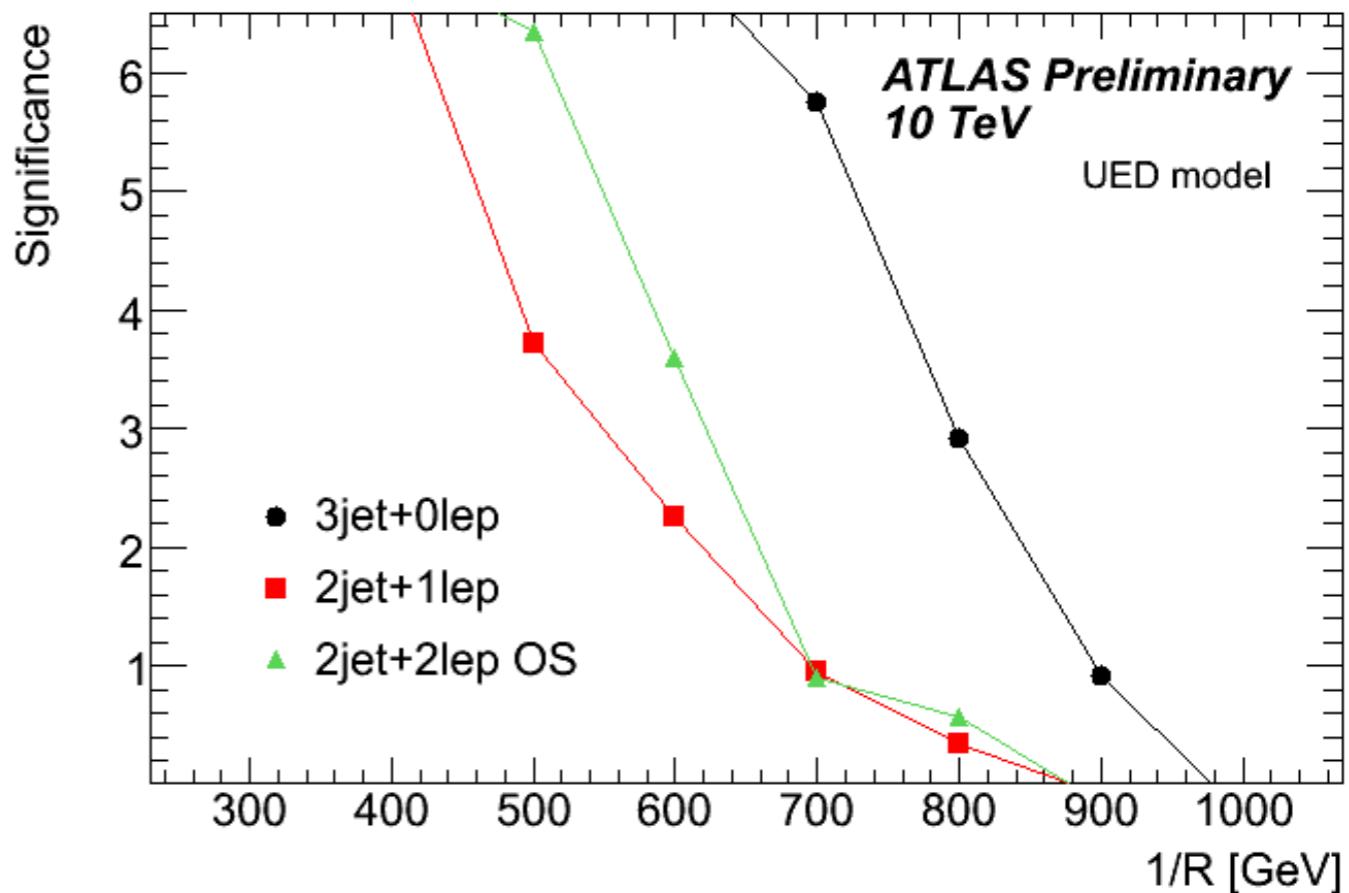
Final Remarks

- LHC and ATLAS has performed remarkably.
- So have simulation and (N)NLO calculations.
- We expect at least 20x more data by end of 2011.
- So expect at large number of inclusive Jets + Leptons + MET searches from ATLAS soon... and throughout the few years.
- We may not be as model independent as possible...
 - we've started...
 - hopefully we'll have the time to incorporate these approaches into our results.

Backup

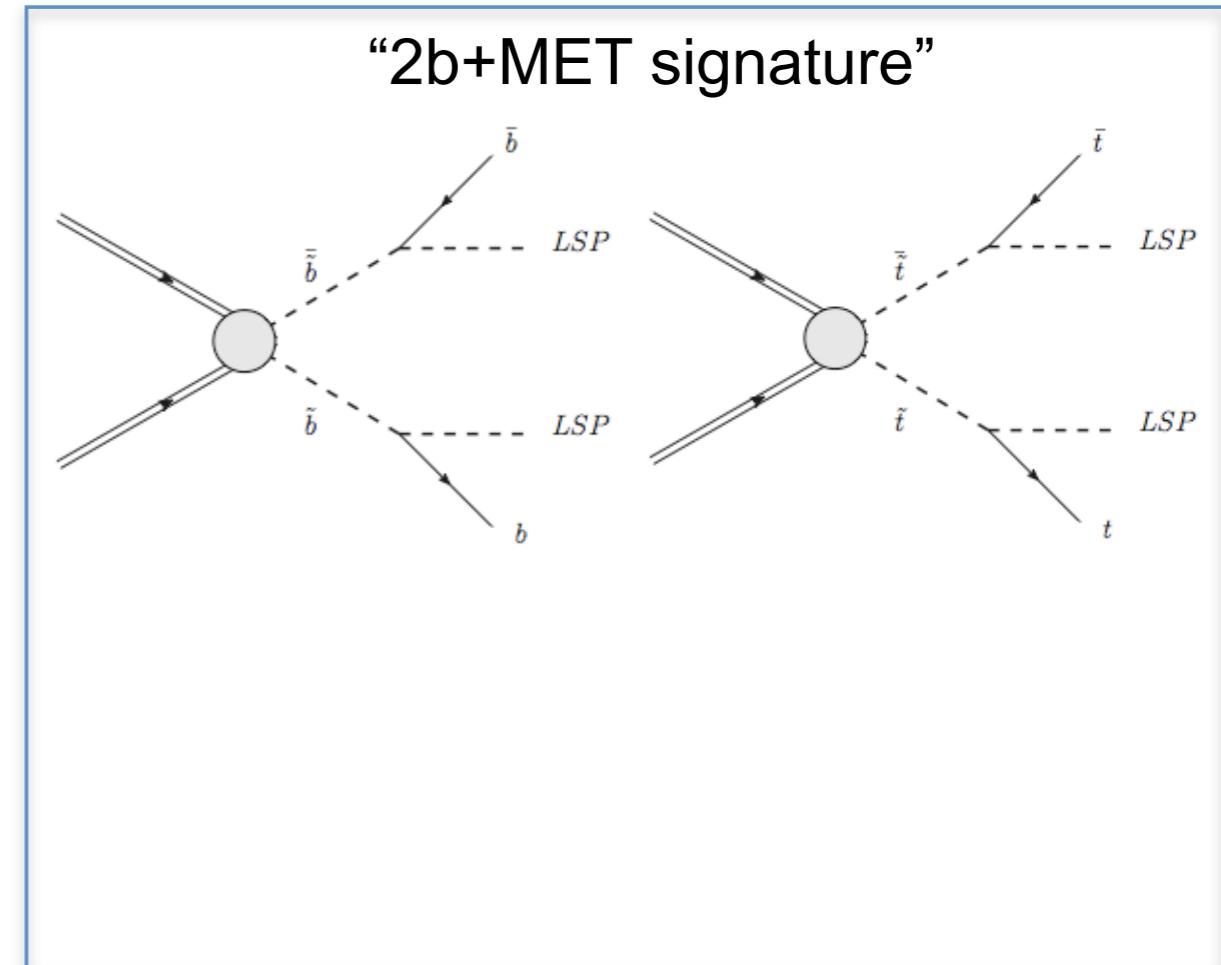
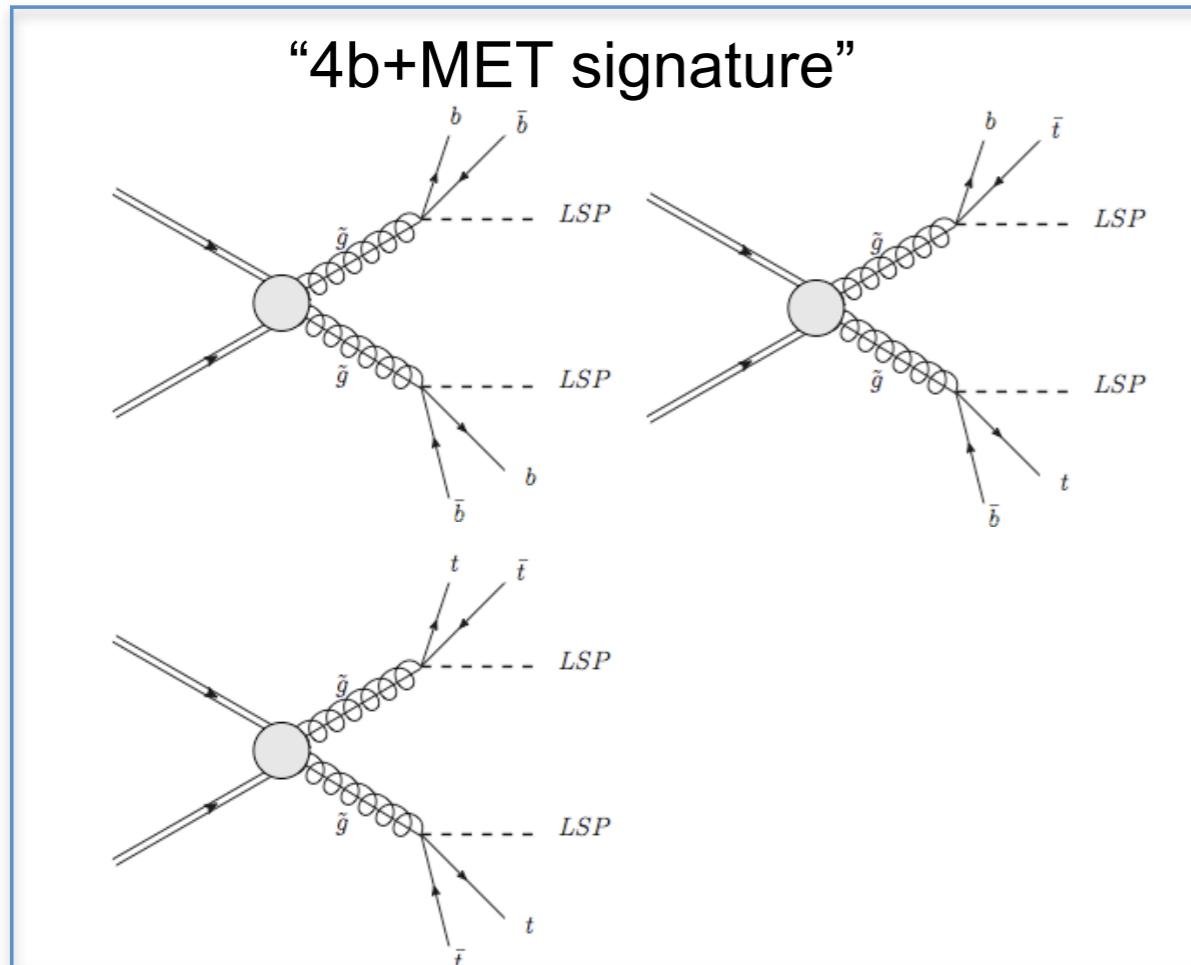
SUSY to UED

- Exact same searches give sensitivity to Minimal Universal Extra Dimensions
 - Provide similar reach in mass scale.
- Though our strategies are often inspired by a model (eg SUSY), our sensitivity is obviously not.



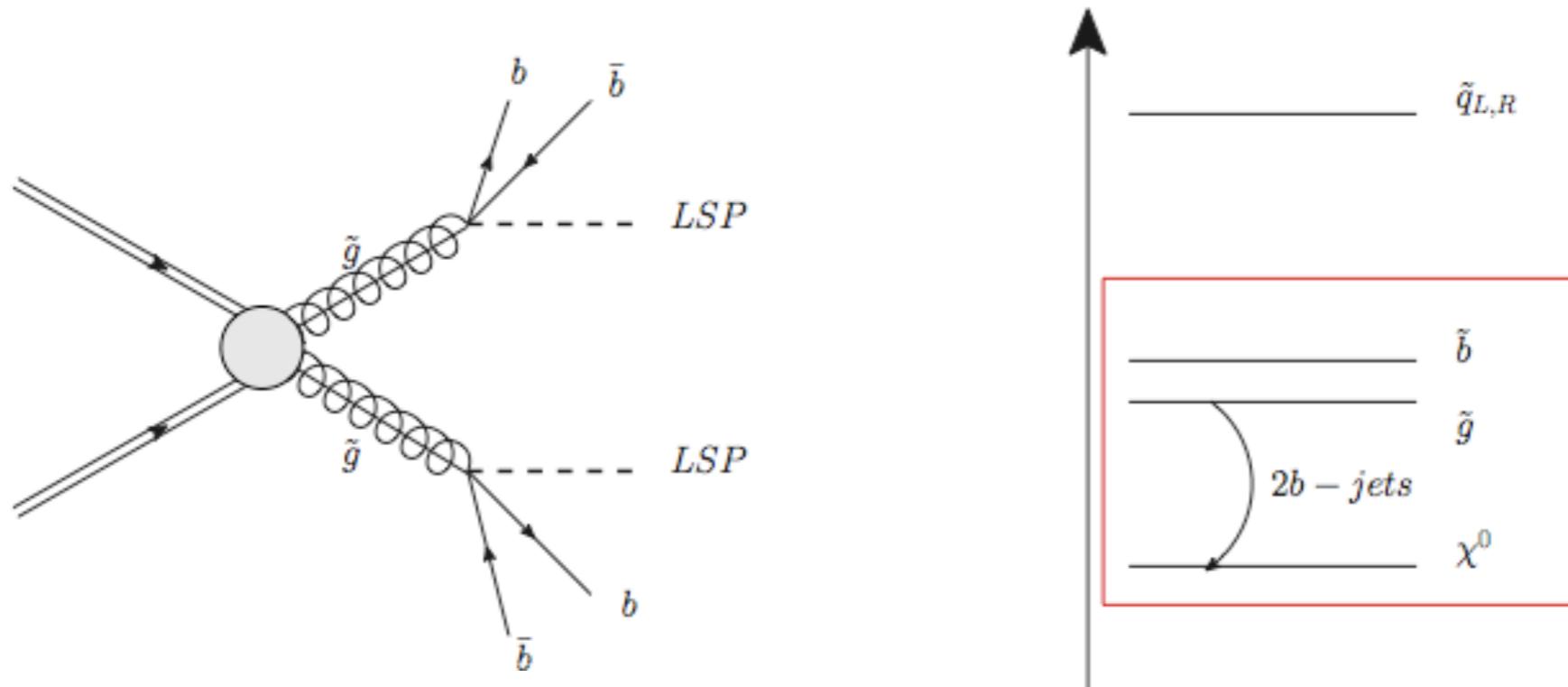
Mapping to Signatures

- Even with heavy flavor restriction, multiple topologies map to each signature
- Here assume 100% branching ratios to b/t (light branching ratio has wider scope)



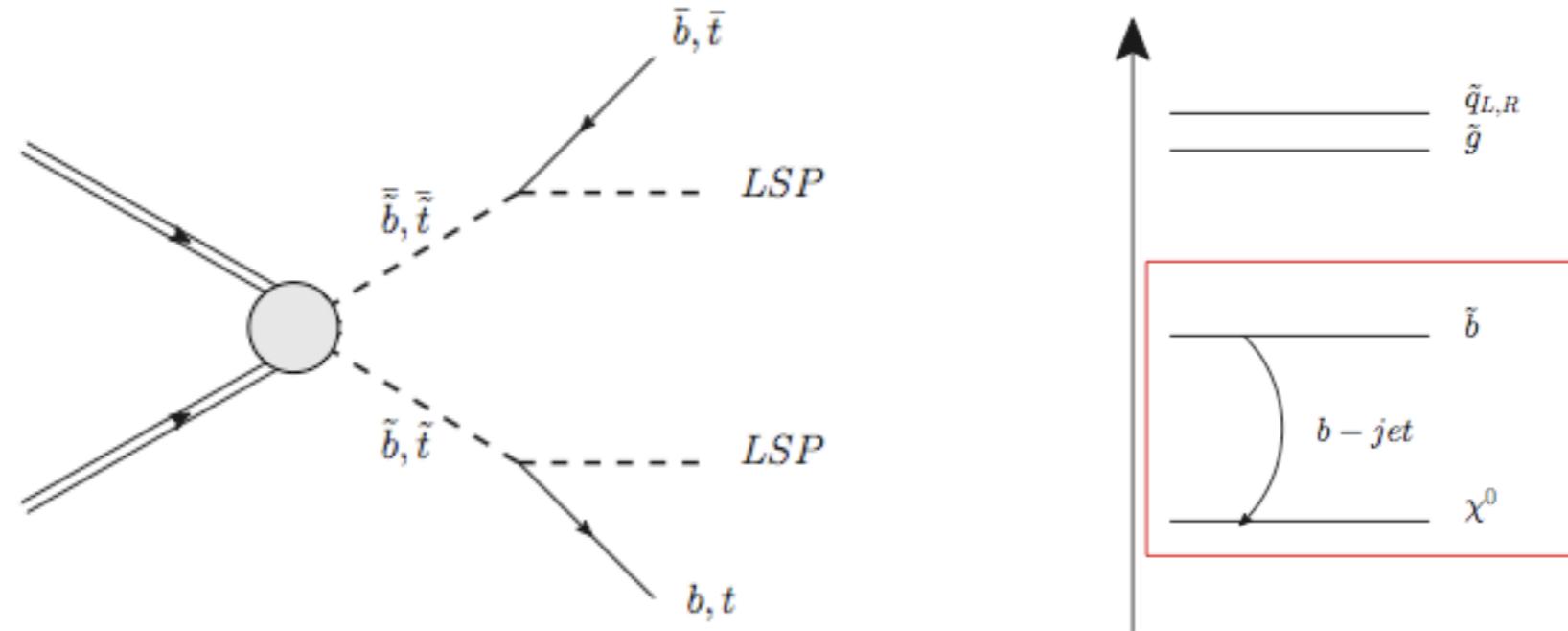
Let's look at the topologies one by one...

Gluino \rightarrow 4b-Jets + MET



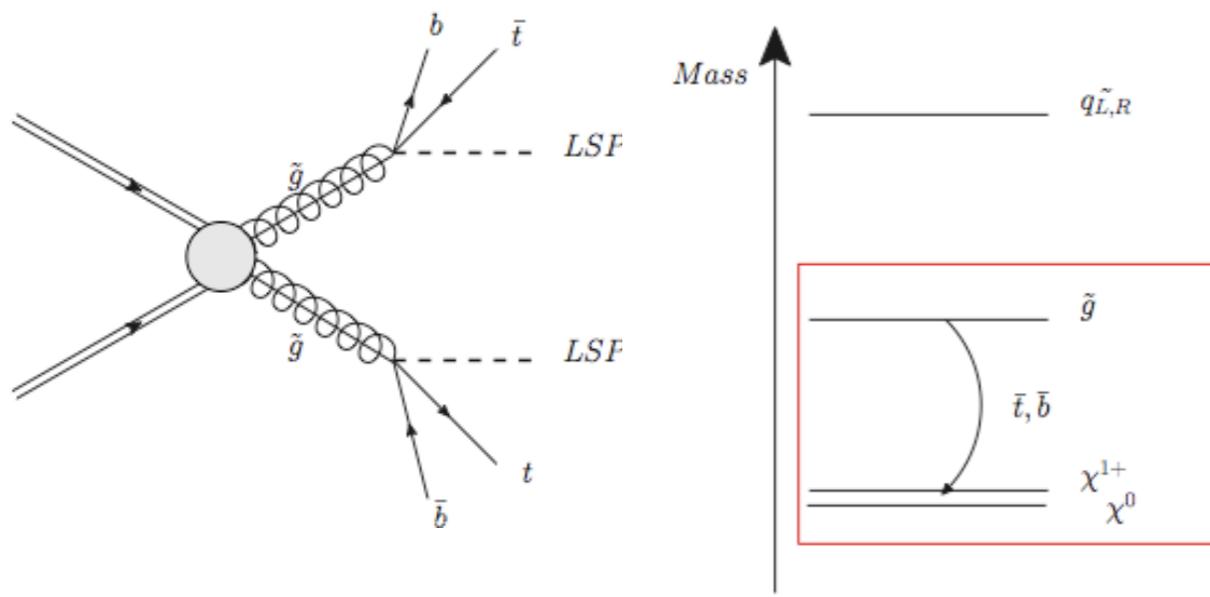
- 4b Jet signature
- We find that:
 - Observables such as Jet pT, M_{eff} , and MET are nearly only sensitive $\Delta M(\sim g, \chi^0)$
 - Gluino mass affects mainly cross-section, not sensitivity
 - All 4 leading jets sensitive to mass difference
 - Expect b-jets with low pT

Squark \rightarrow 2 b-Jets + MET



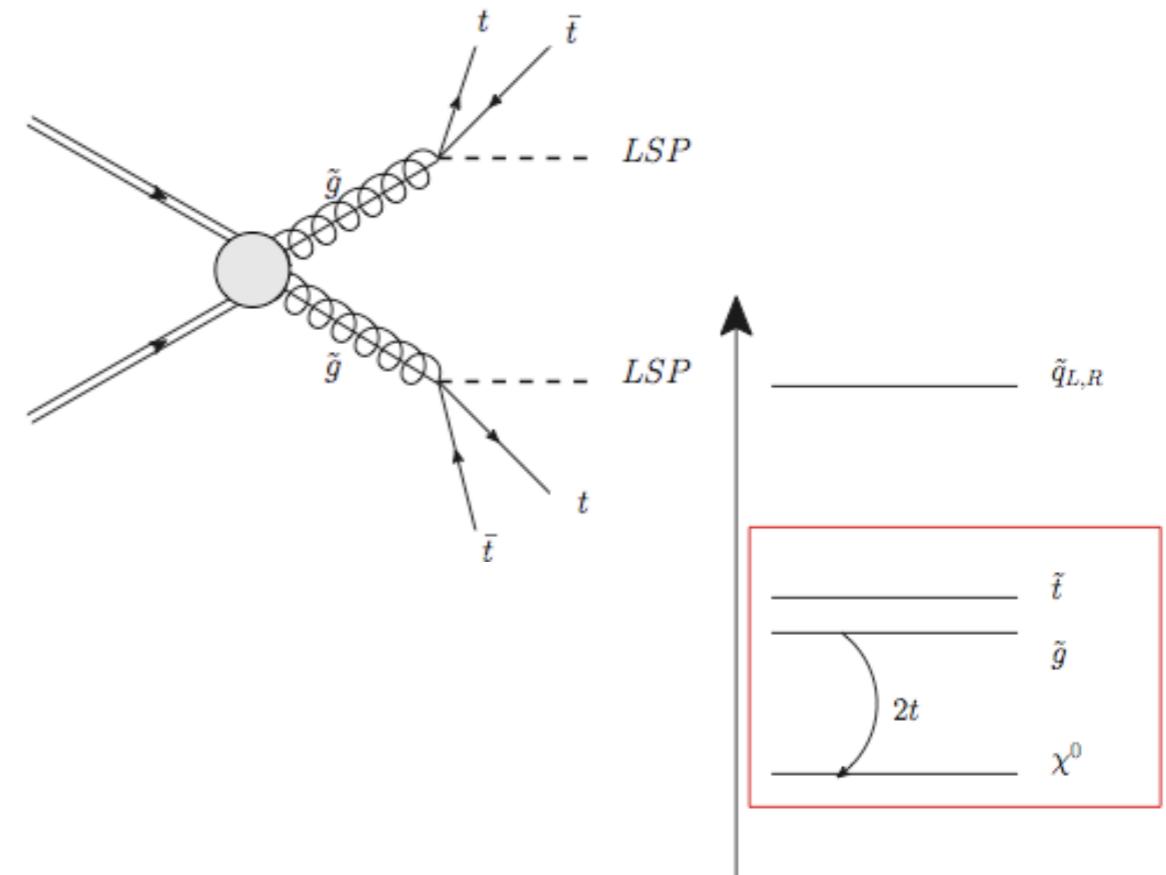
- Considered 2 b-jet signature only
 - 2 stop prod: more complicated final state is possible -> softer b-jets
- We find that:
 - Observables such as Jet pT, M_{eff} , and MET are nearly only sensitive to $\Delta M(\sim b, \chi^0)$
 - Squark (partner) mass determines x-section, not sensitivity
 - Two (b-)jets sensitive to mass difference
 - Additional light jets not sensitive to mass difference (see 4th leading jet pT)
 - Low overall jet multiplicity: largely unaffected by mass difference

Gluino \rightarrow t/b-Jets + MET



- 2b2t + MET
- 4 b-jet signature
- Top production creates more complicated final state
 - Softer b-jets
 - Higher light jet multiplicity
- $\Delta M(\sim g, \chi^0)$ still main parameter for jet and MET kinematics
- Might expect two hard and two softer b-jets

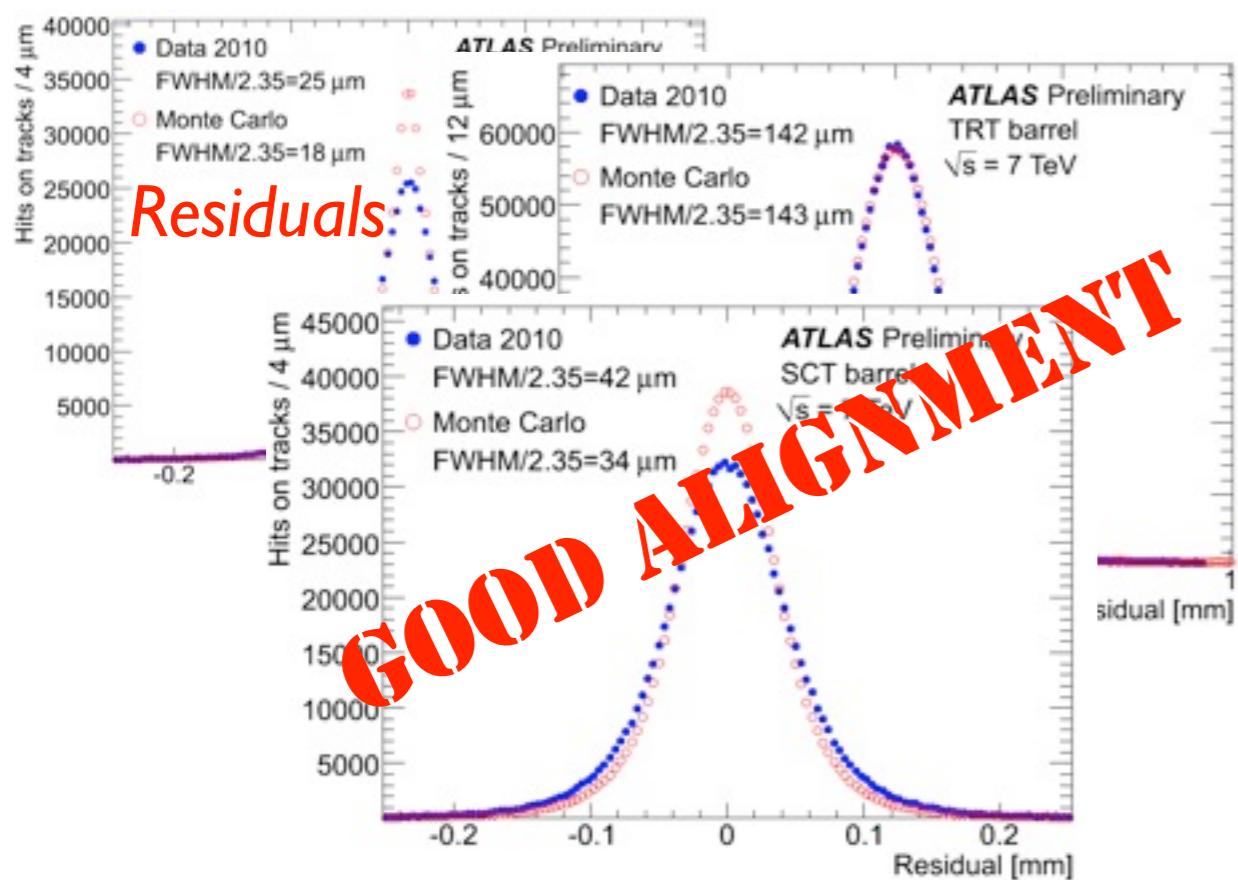
- 4t + MET
- 4 b-jet + MET signature
- $\Delta M(\sim g, \chi^0)$ determines available jet and LSP kinematics
- Moderated by top decay \rightarrow expect less sensitivity to mass difference
 - Softer b-jets
 - High (light) jet multiplicity (low pT)
- Requires rather large gluino partner mass



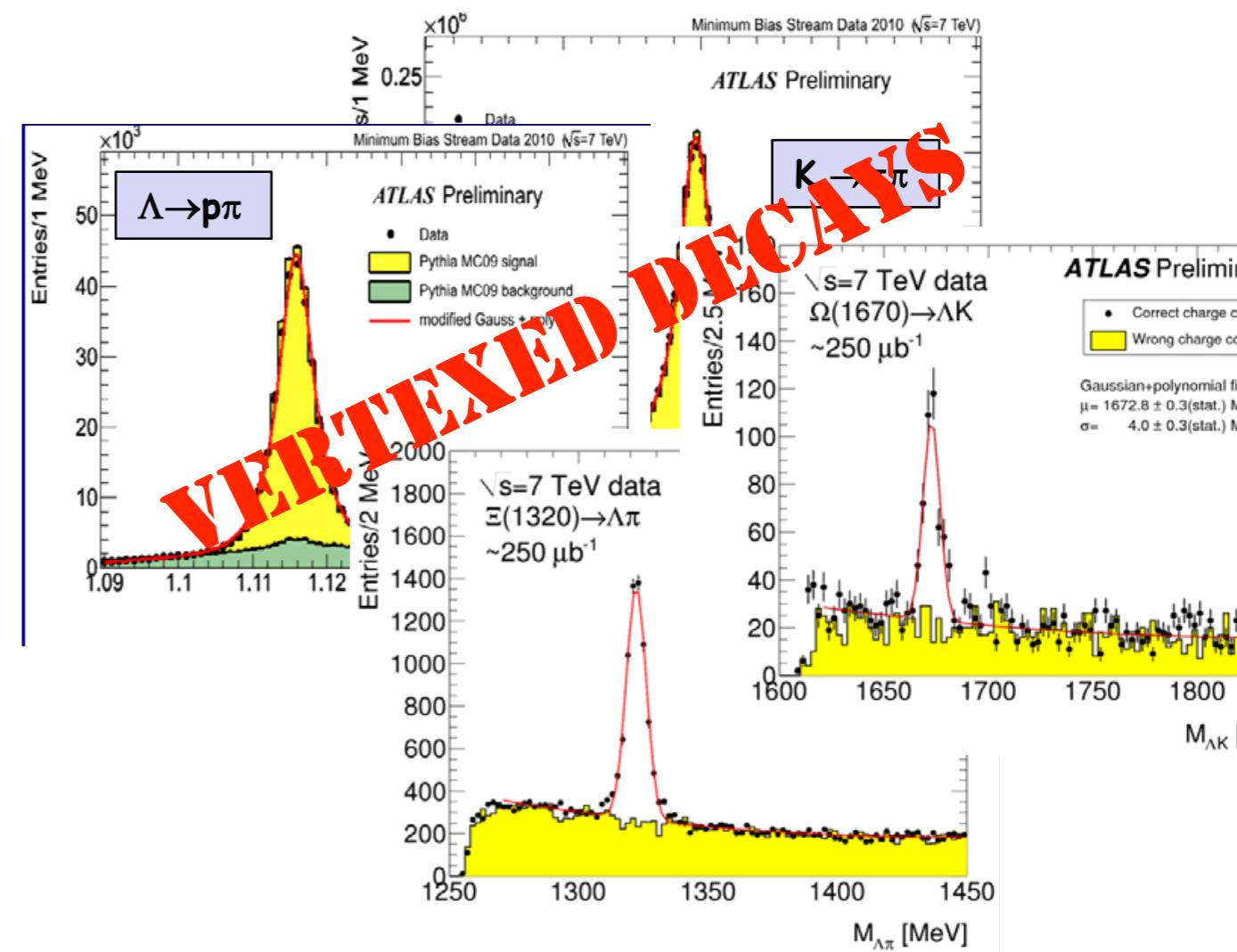
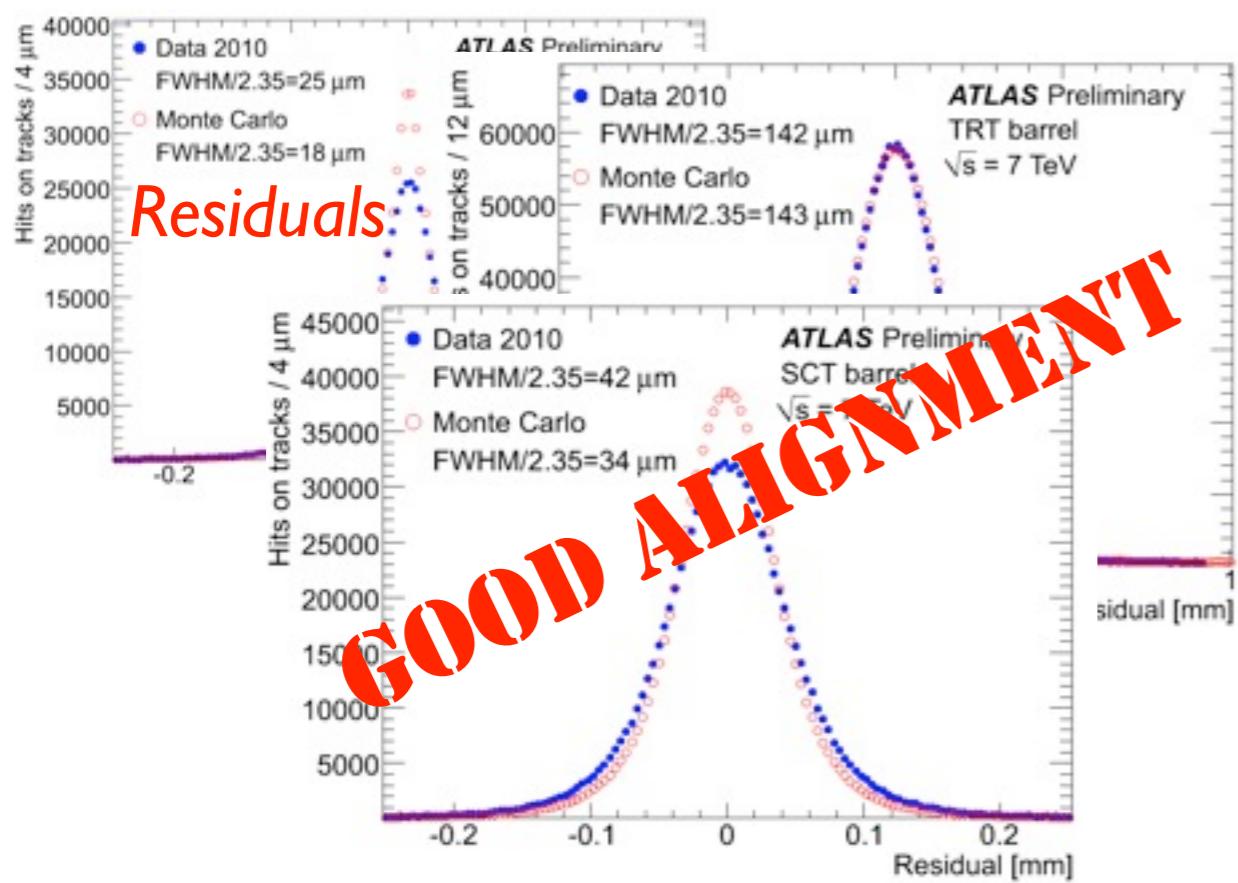
Sub-system Performance

Inner-Detector

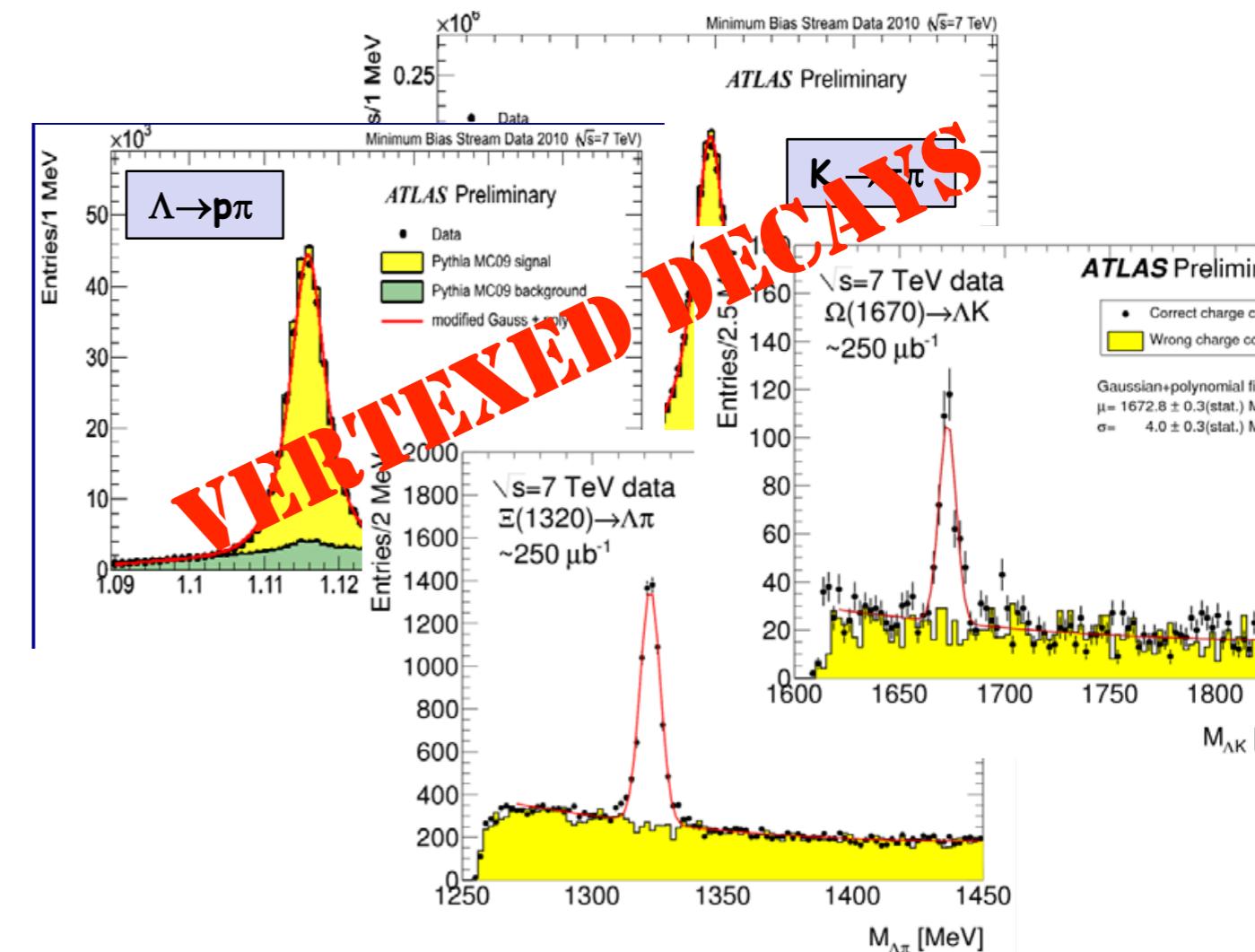
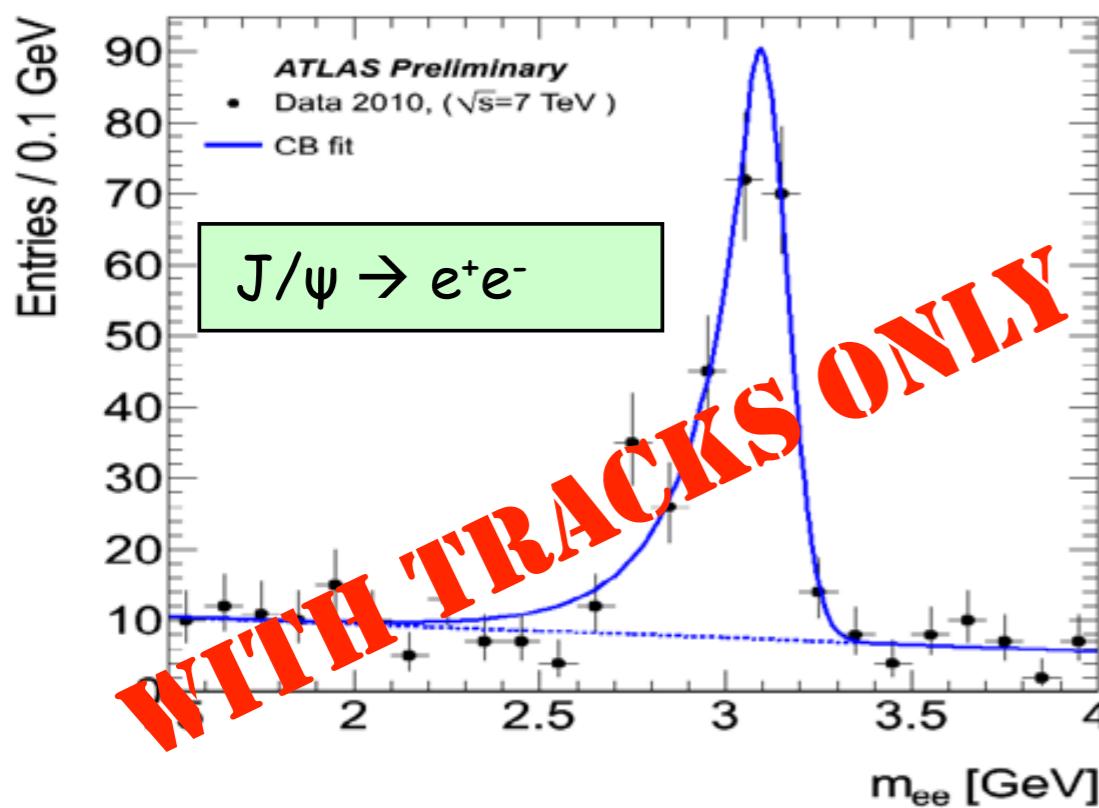
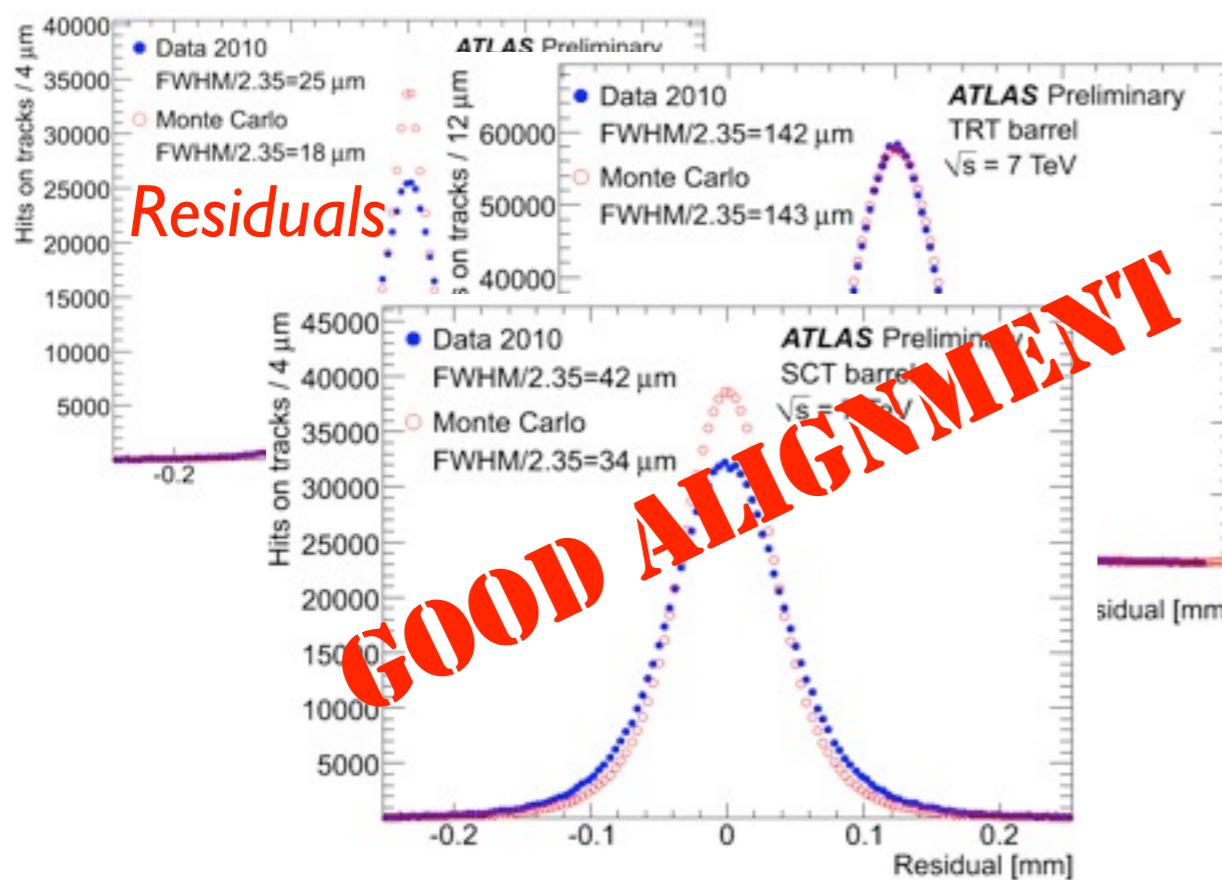
Inner-Detector



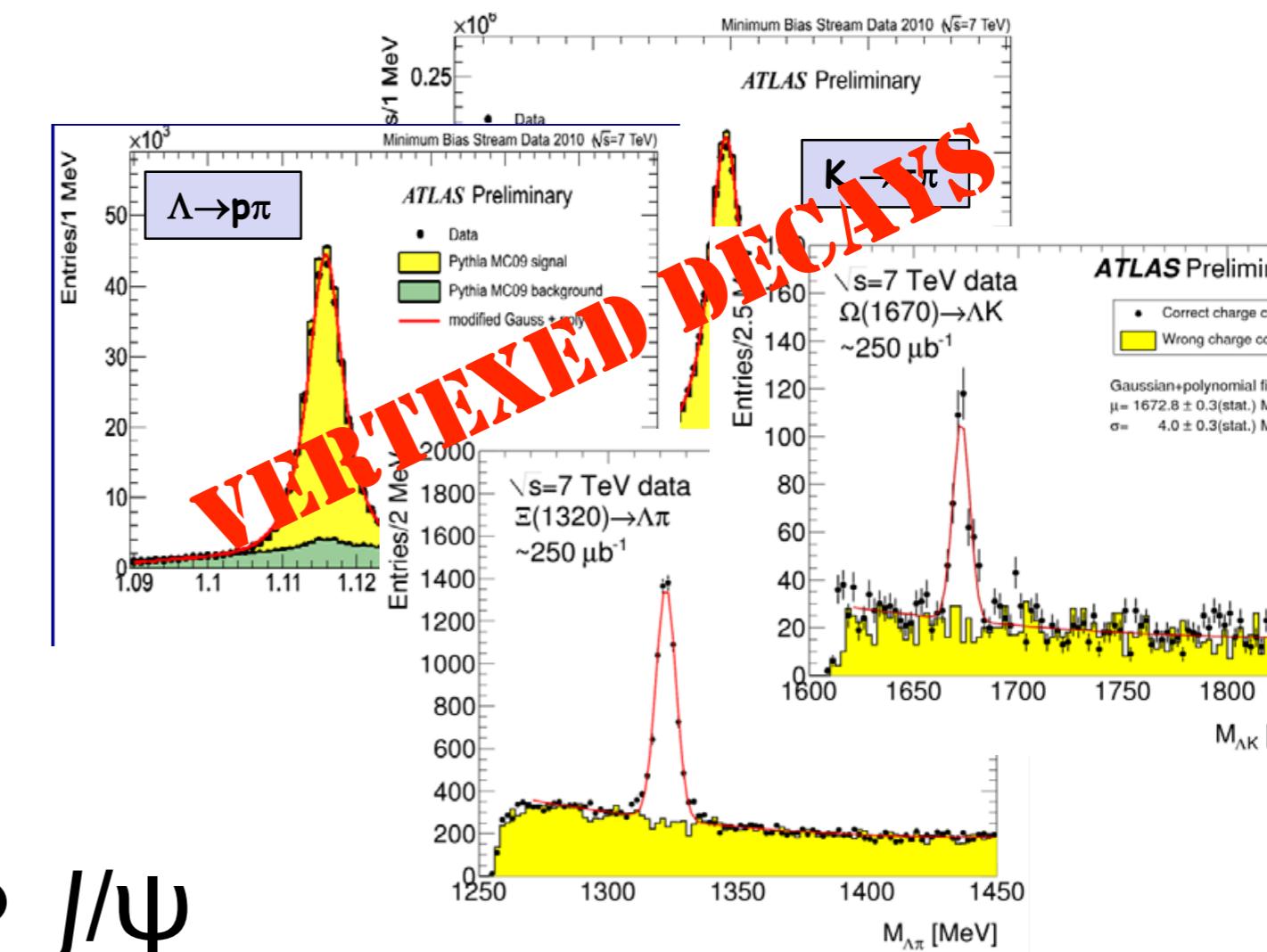
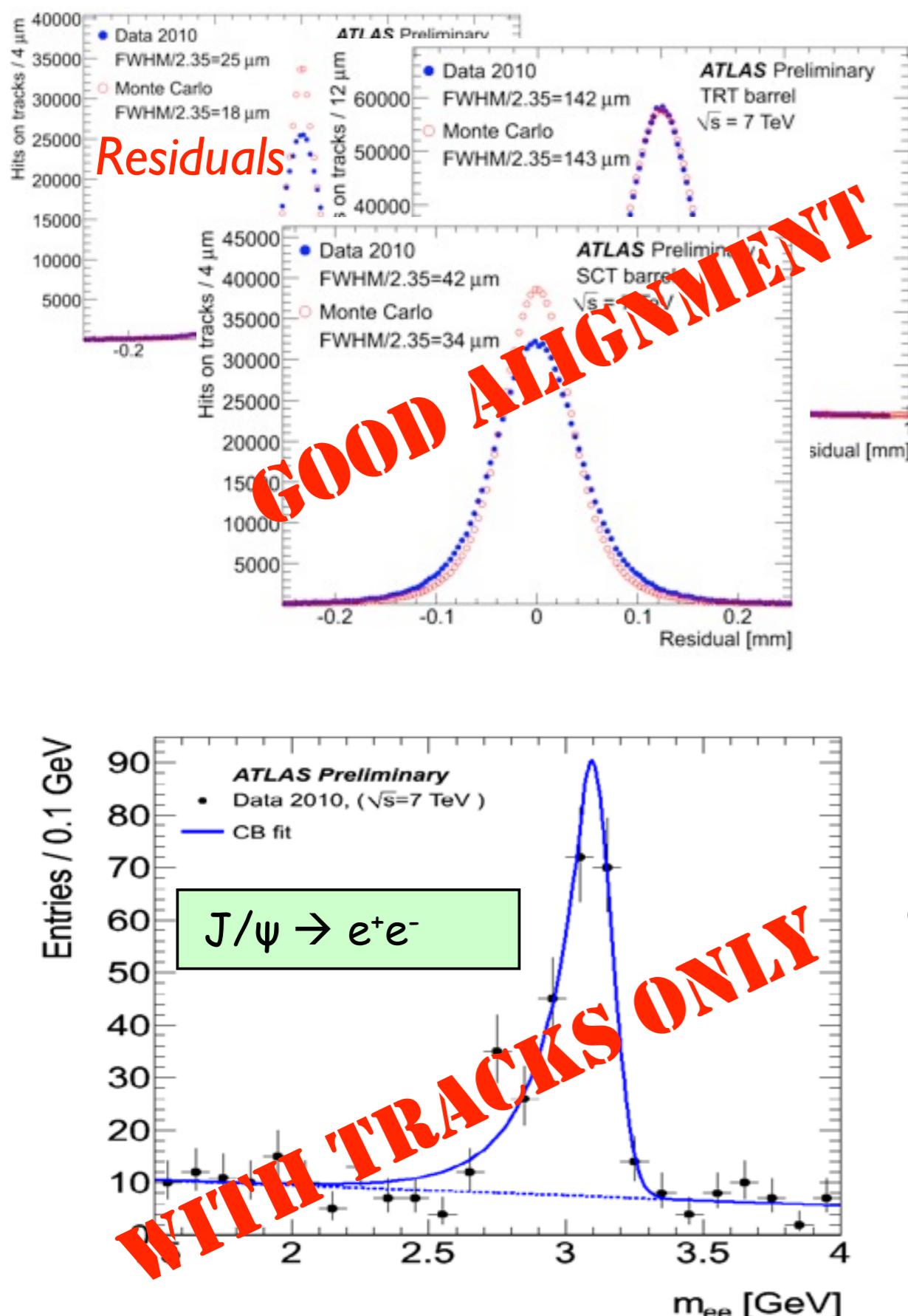
Inner-Detector



Inner-Detector



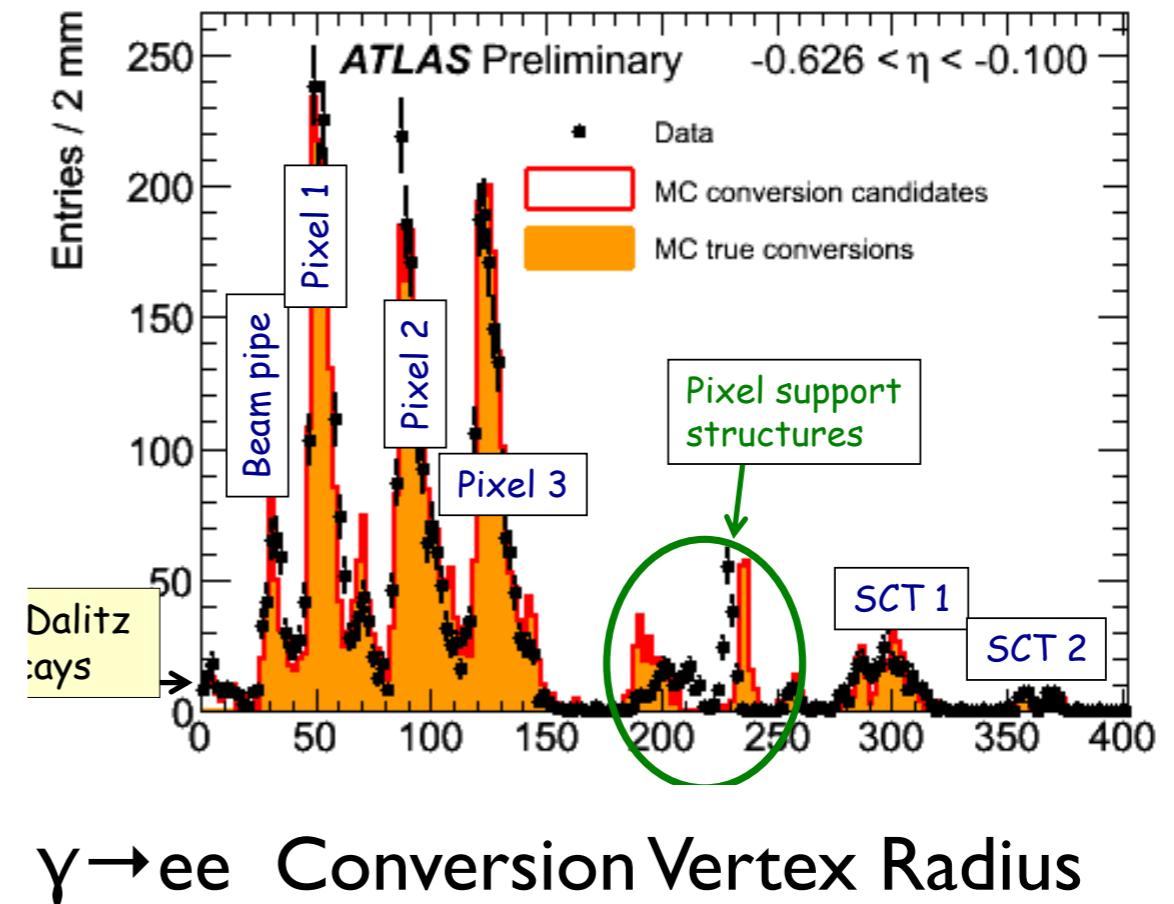
Inner-Detector



- J/ψ
 - $\text{Sig/Bkg} = 222 \pm 11 / 28 \pm 2$ events
 - Mass Mean/Res: $3.09 \pm 0.01 / 0.07 \pm 0.01$ GeV

Material

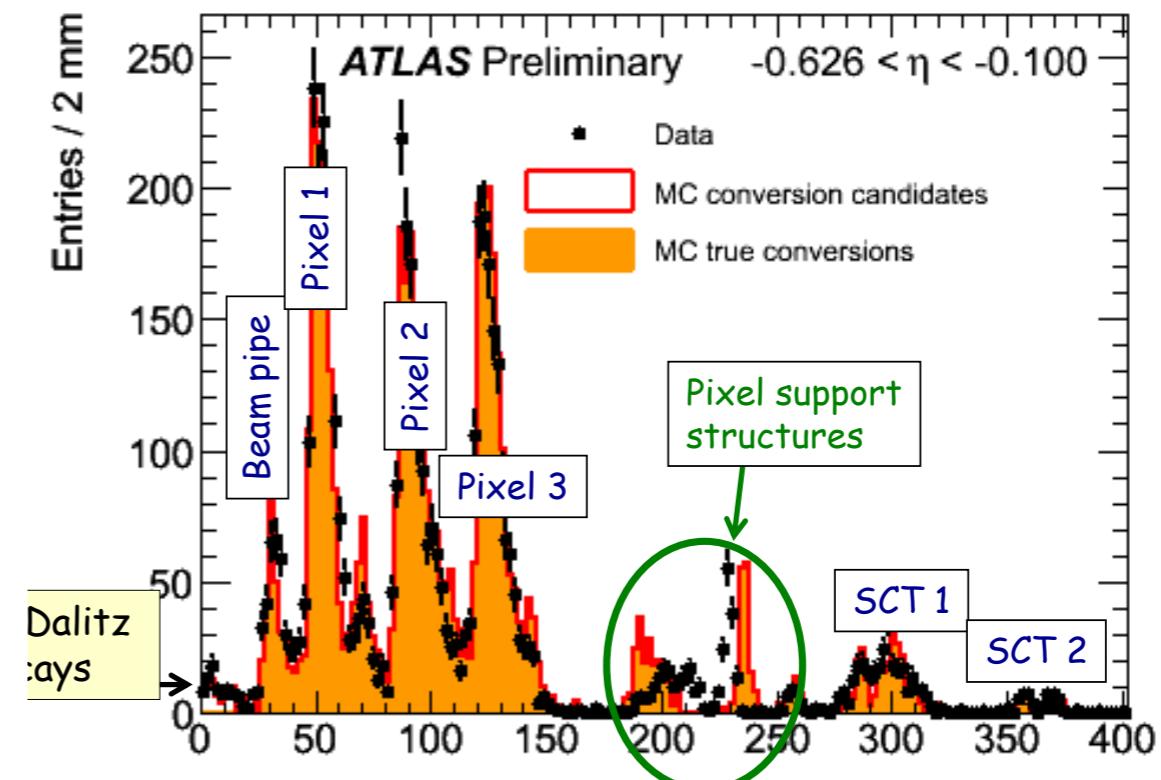
- *Goal is to know Material better than 5%...*
- *Currently 10%*



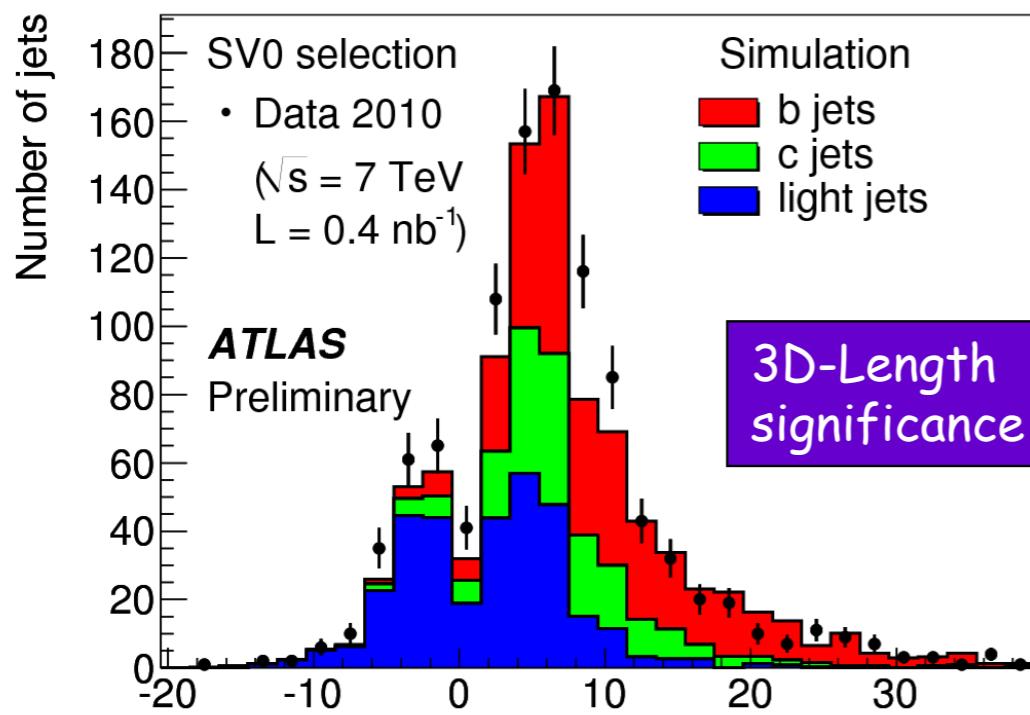
$\gamma \rightarrow ee$ Conversion Vertex Radius

Material

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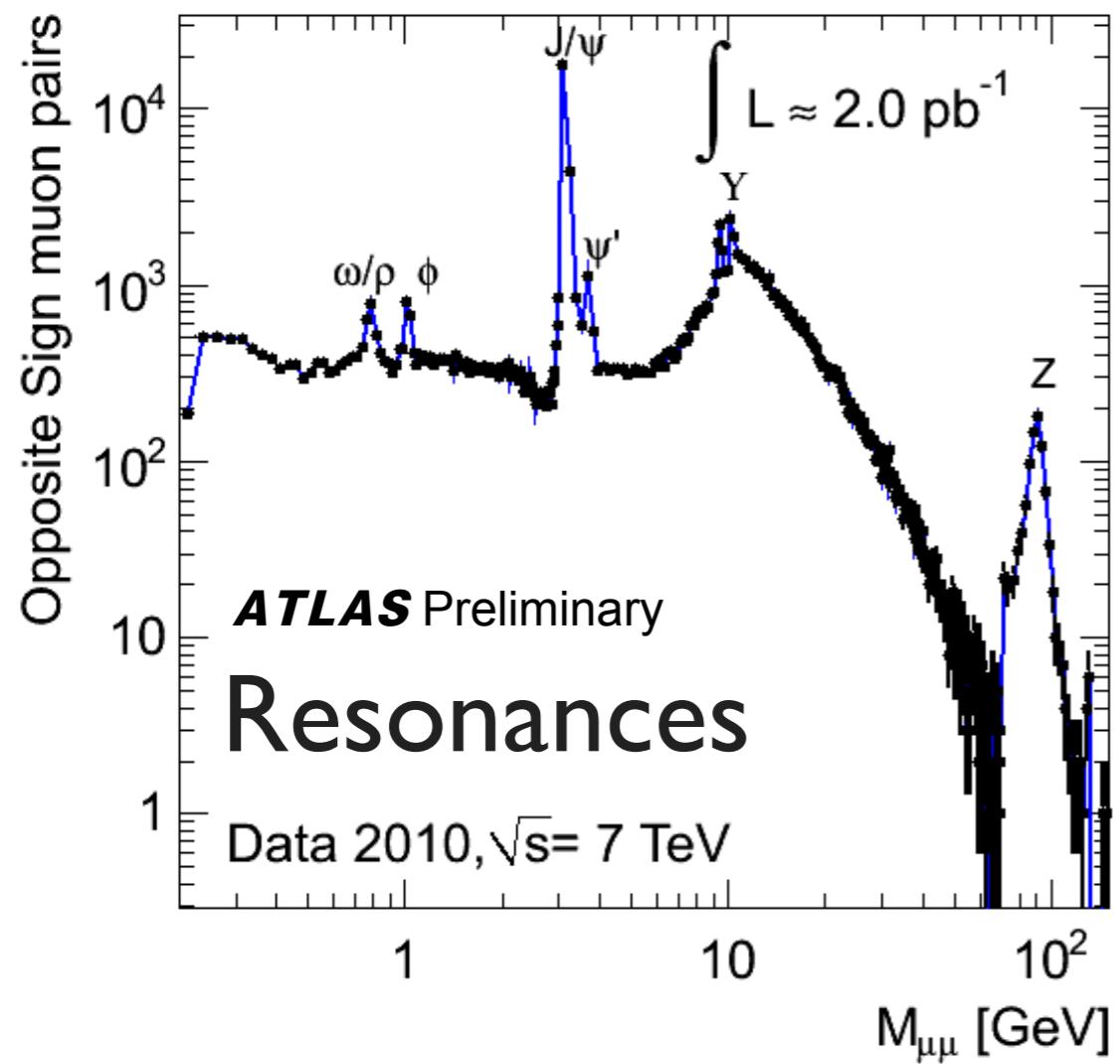
$\gamma \rightarrow ee$ Conversion Vertex Radius



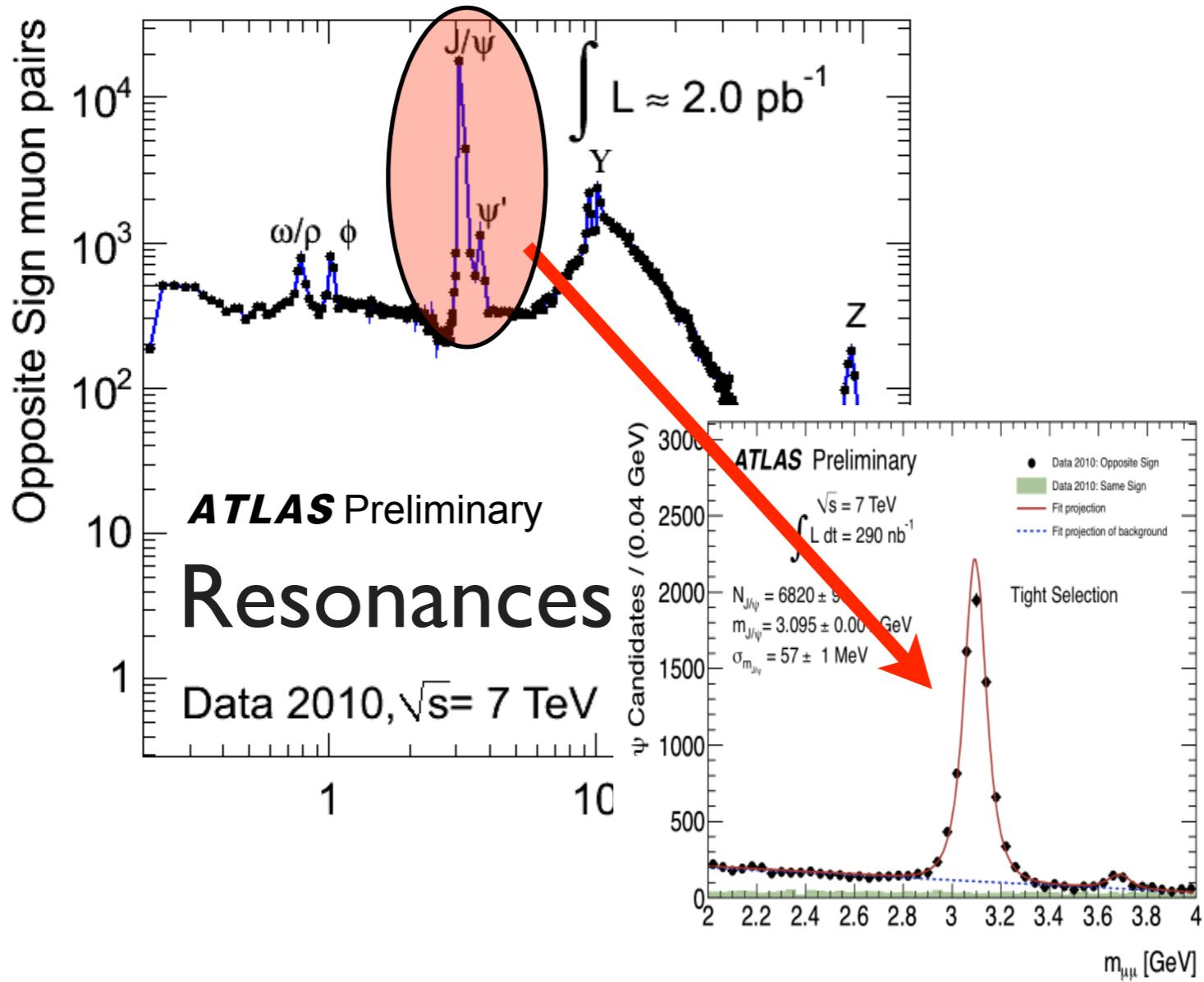
- ## b-Tag
- Rejection at 50% Eff =
 - >98% (light), >80%(charm)
 - Improvement after reprocessing due to new alignment

Muons

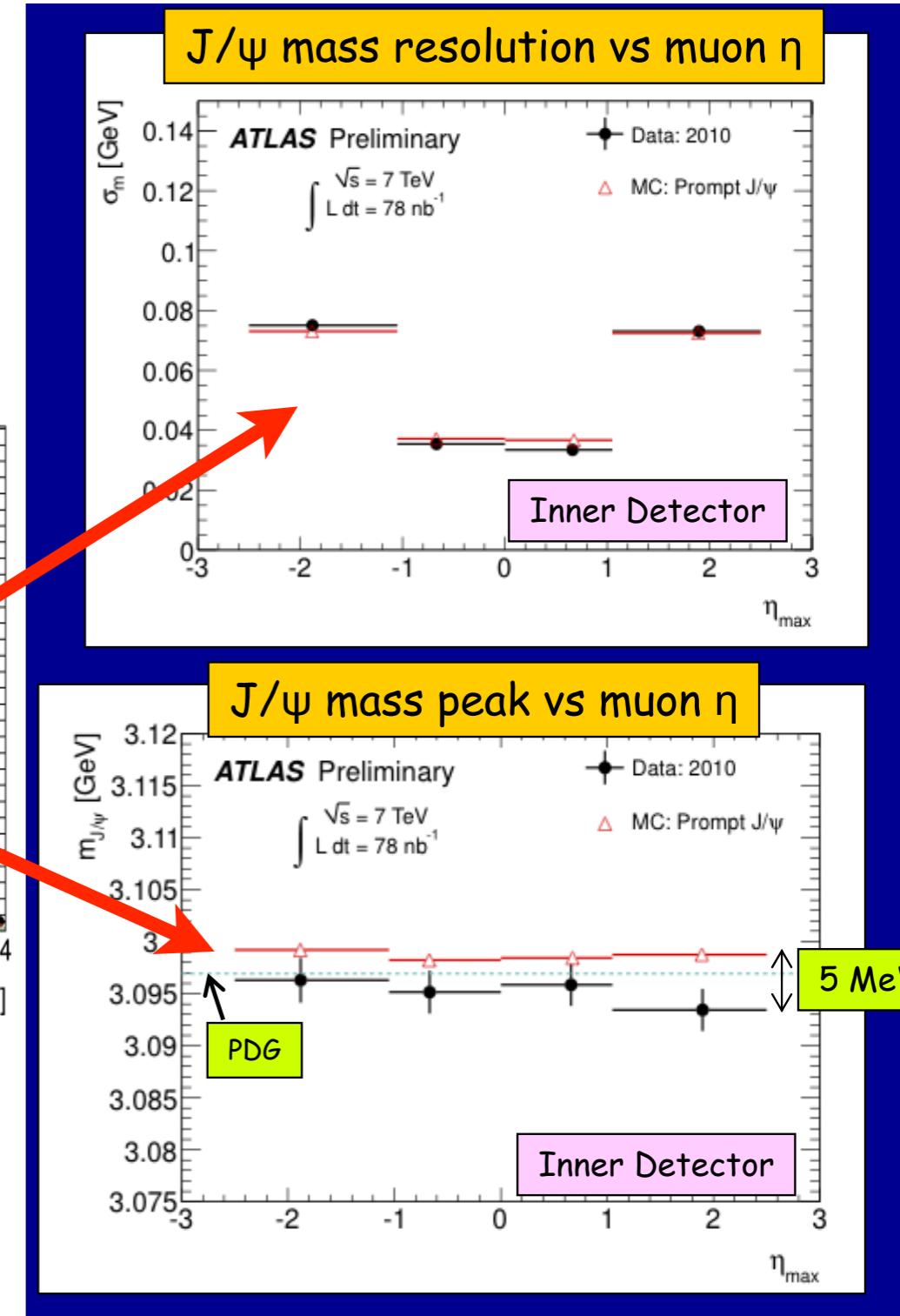
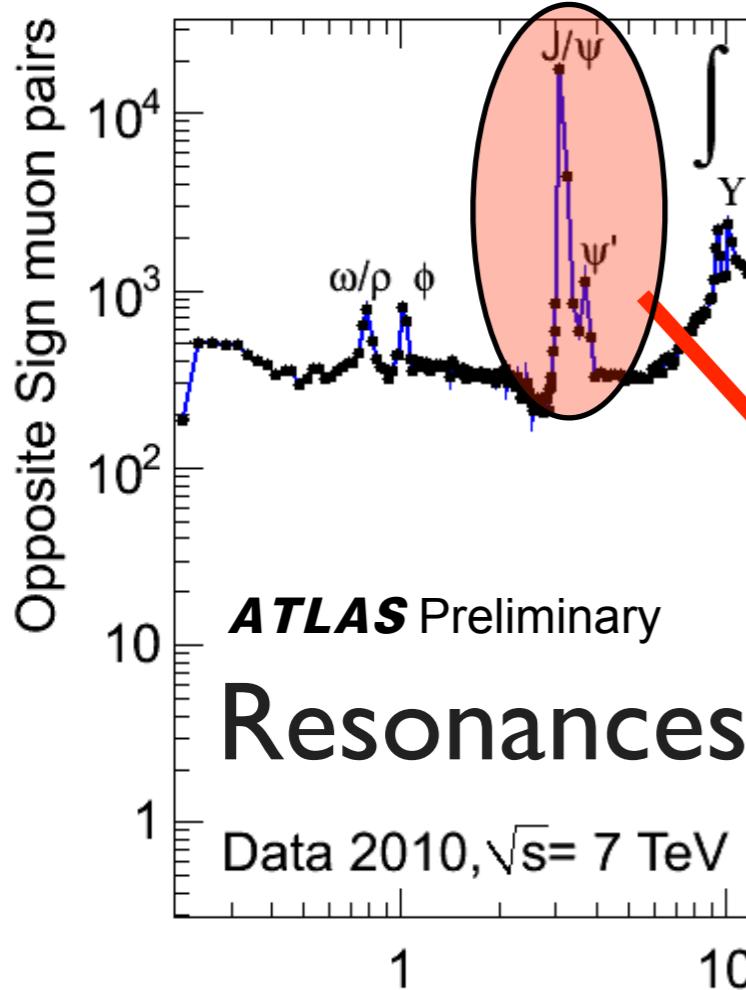
Muons



Muons



Muons



- From J/ψ :
- Absolute momentum scale known to $\sim 0.2\%$
- Momentum resolution to $\sim 2\%$ in the few GeV region

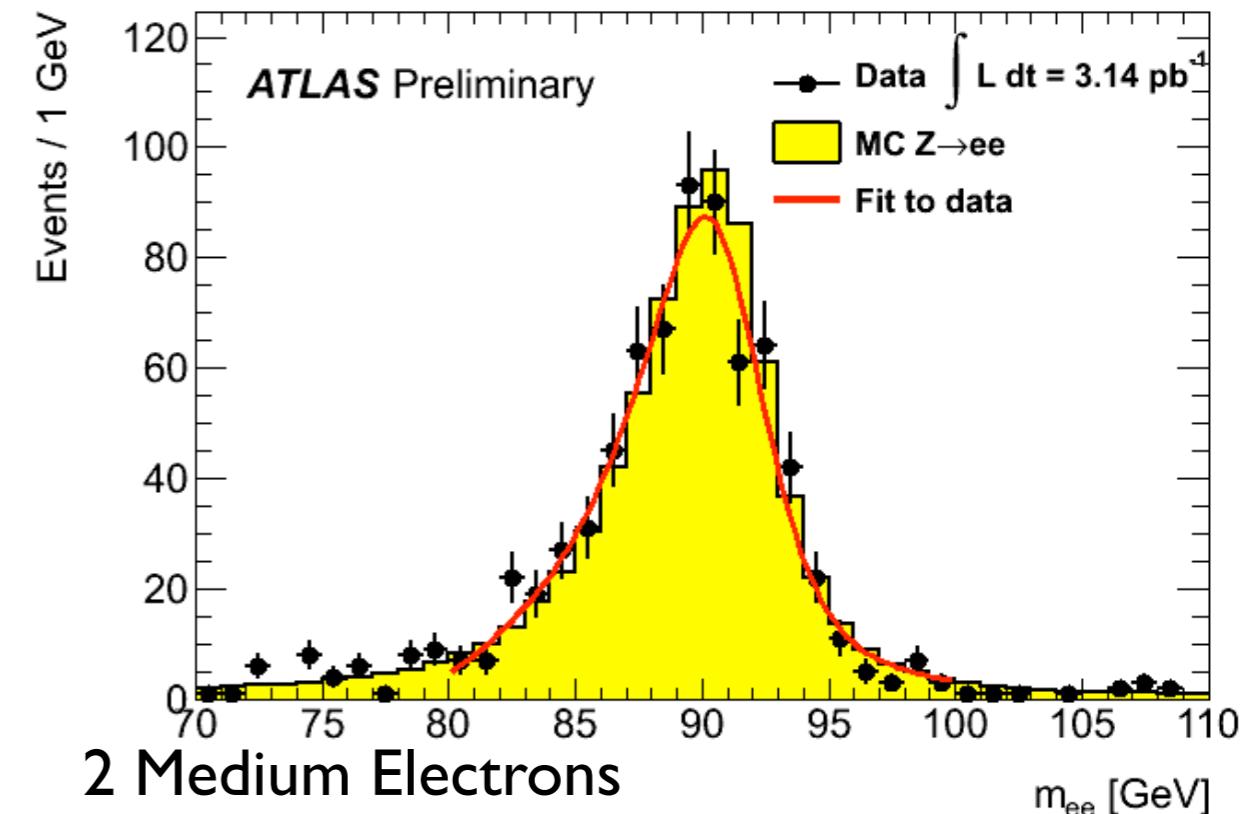
Electrons

Electrons

- *Many handles for identification:*
 - *loose:* rough shower shape and track
 - *medium:* ref shower shape, pixel hit, d0
 - *tight:* track match, transition radiation, E/p
- *Tight (>20 GeV) $\sim 10^5$ Jet rejection*
- *Initial E-scale transported from test-beam with help from MC*
- *Inter-calibration Checked (to $\sim 2\%$) with π^0 's and Z's*

Electrons

- Many handles for identification:
 - loose: rough shower shape and track
 - medium: ref shower shape, pixel hit, d0
 - tight: track match, transition radiation, E/p
- Tight (>20 GeV) $\sim 10^5$ Jet rejection
- Initial E -scale transported from test-beam with help from MC
- Inter-calibration Checked (to $\sim 2\%$) with π^0 's and Z 's



- Z Resolution:
 - $\sigma(\text{data}) = 1.59 \pm 0.04$ GeV
 - $\sigma(\text{MC}) = 1.40 \pm 0.01$ GeV

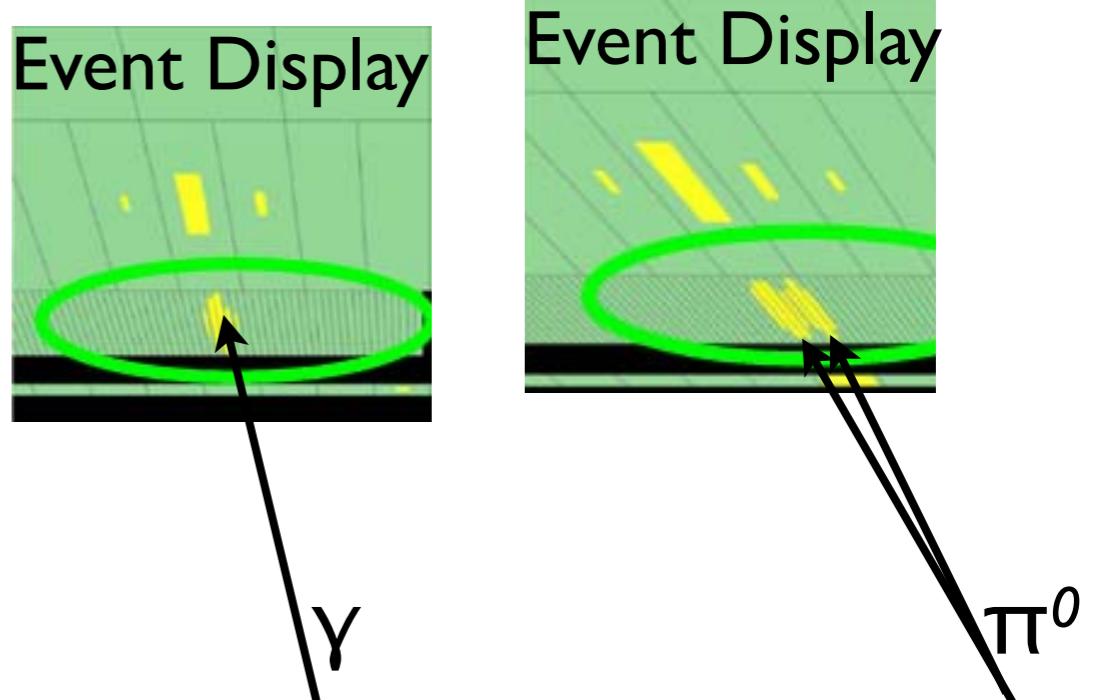
Photons

Photons

- *Tight Selection tuned to match MC:*
 - rely heavily on shower structure in strip section
 - completed by isolation
- *Jet rejection (leading π^0) less effective than for electrons*
 - *Retuning / better performance coming soon.*

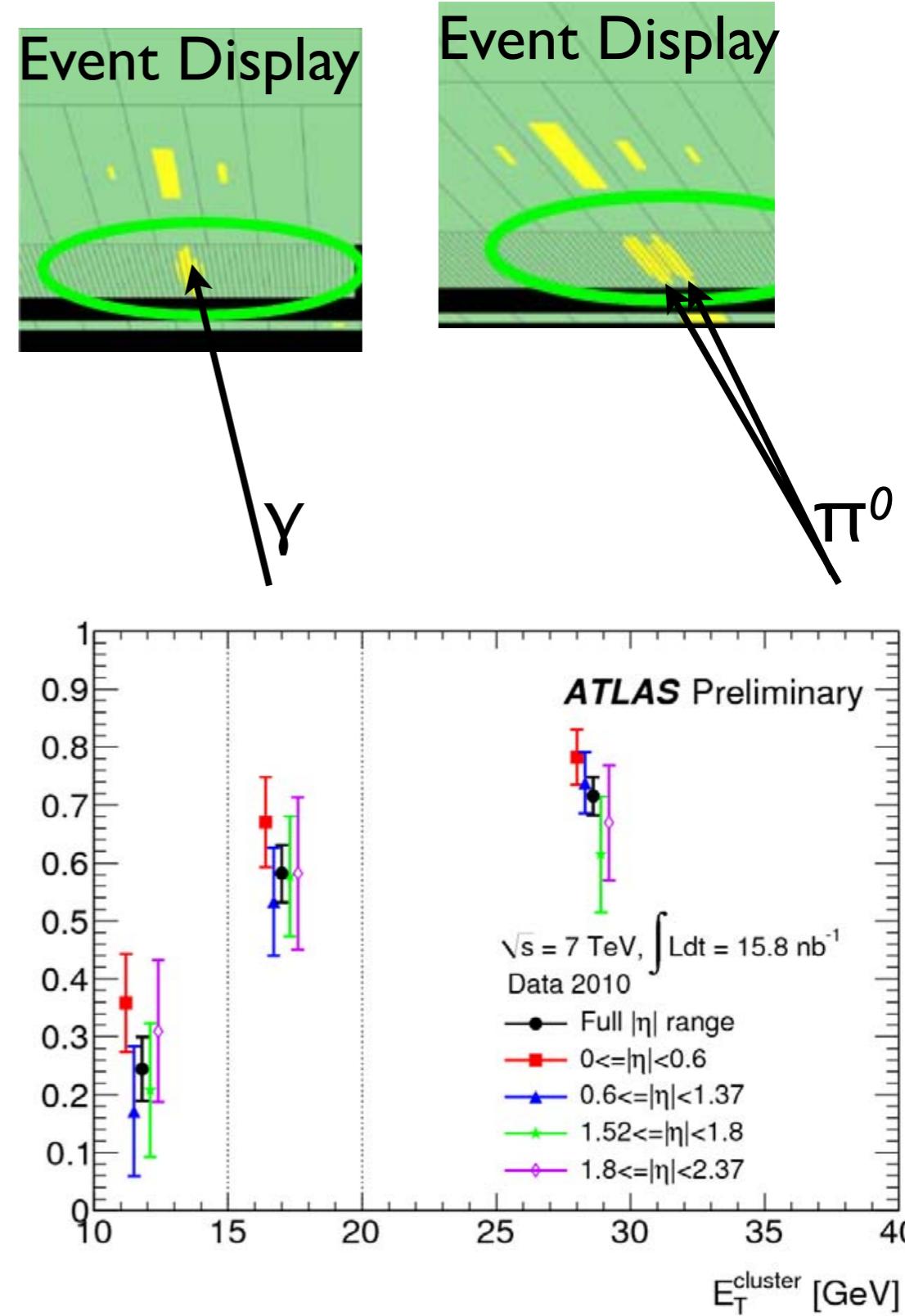
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Photons

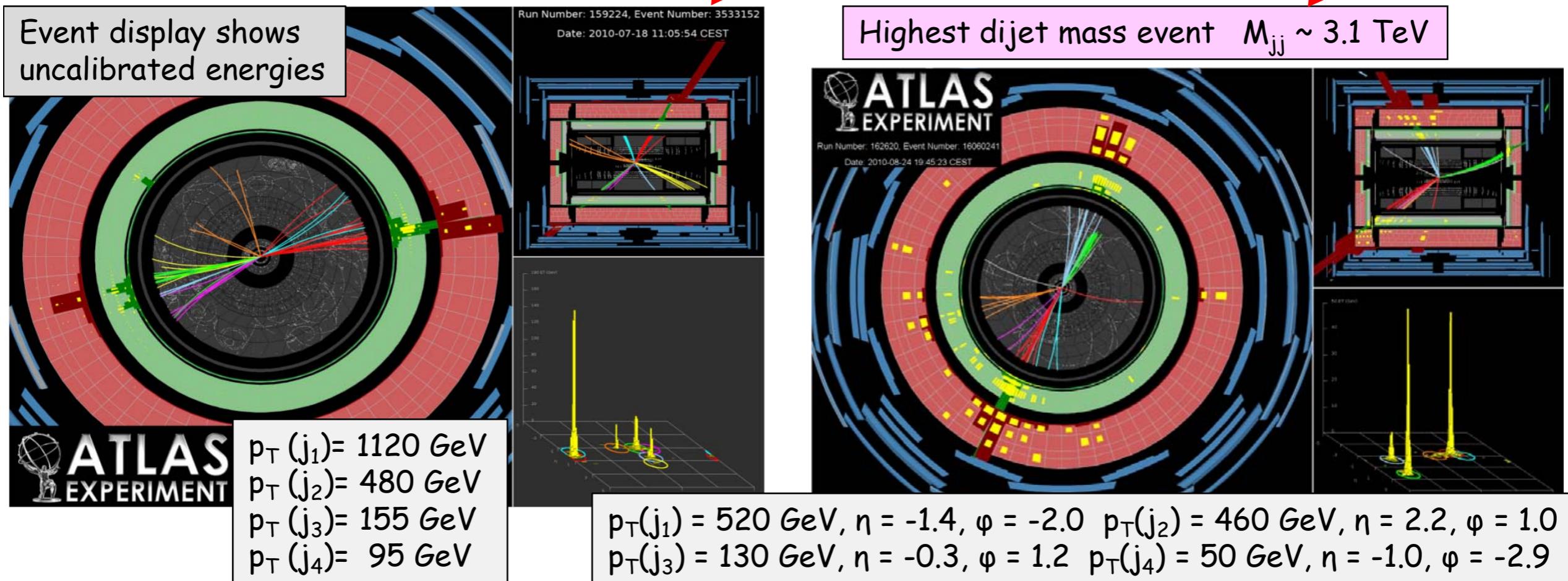
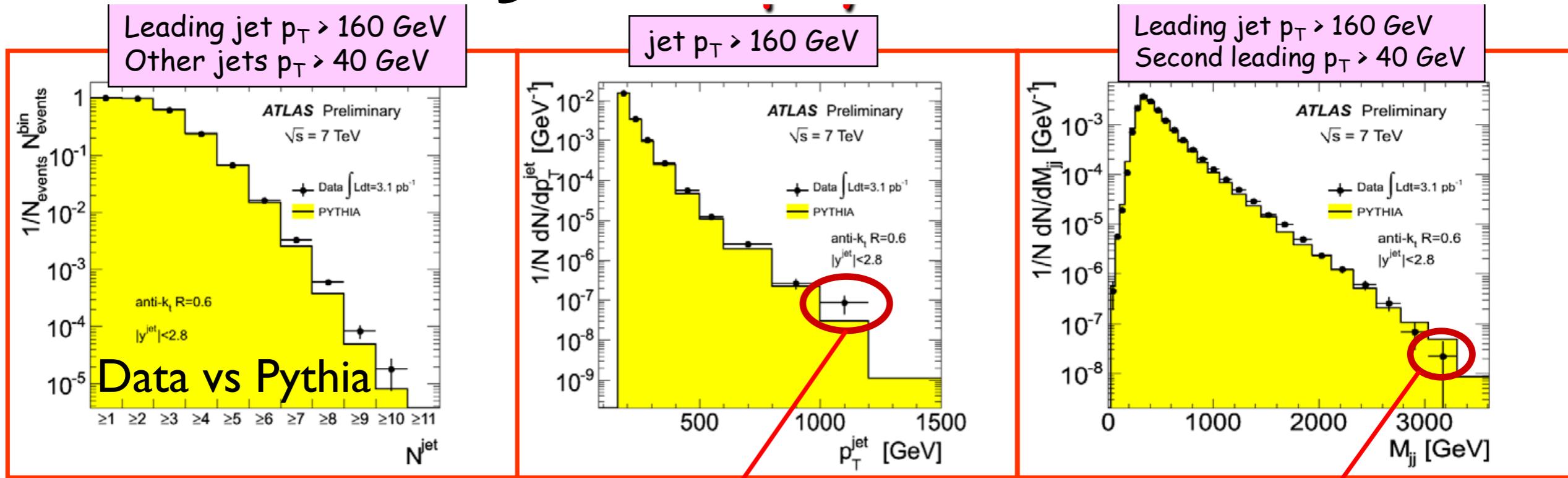
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Standard Model

Jet Events

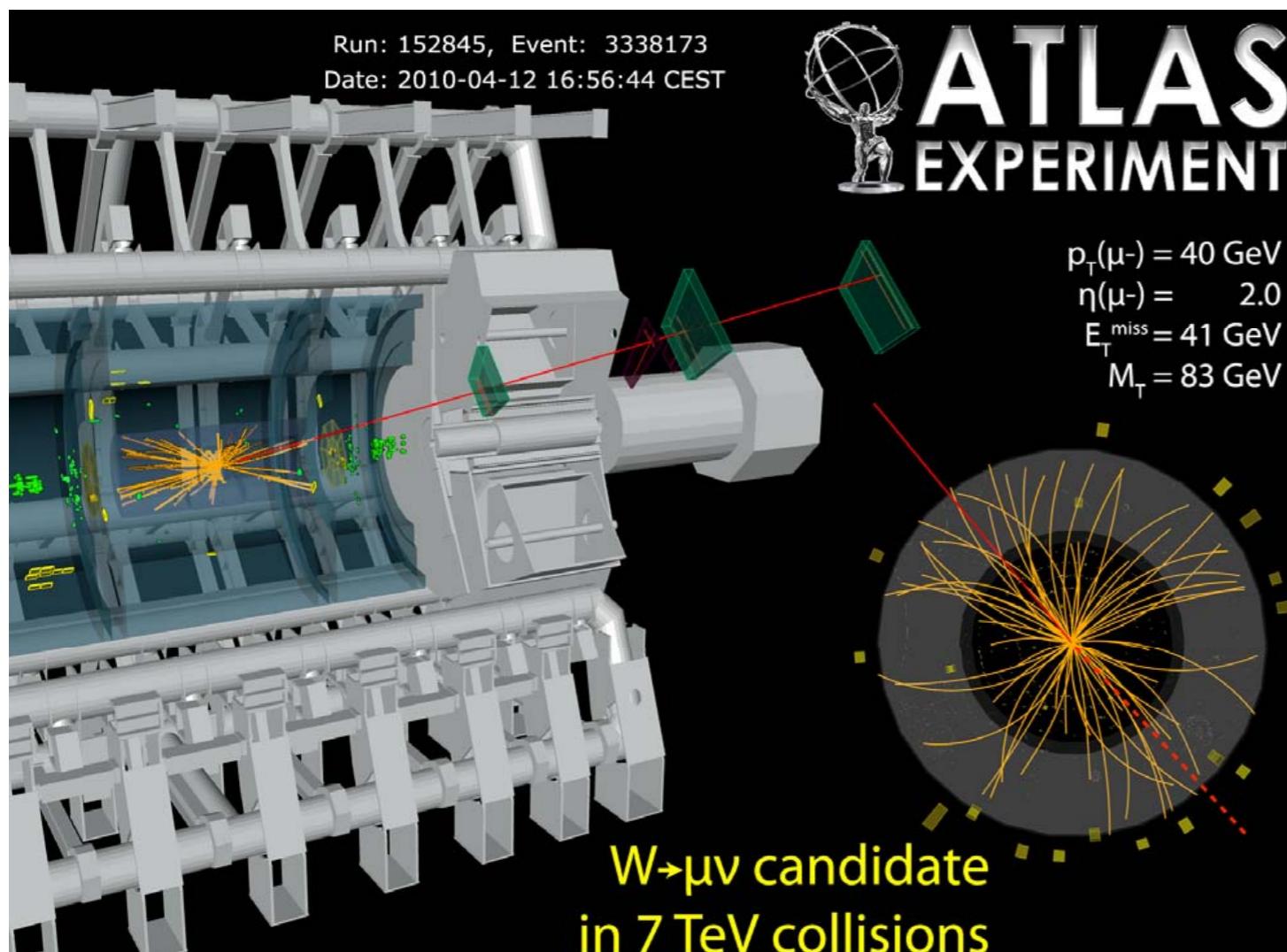
Jet Events



W/Z

W/Z

- Fundamental milestones in the “rediscovery” of the Standard Model at $\sqrt{s} = 7 \text{ TeV}$
- Powerful tools to constrain q,g distributions inside proton (PDF)

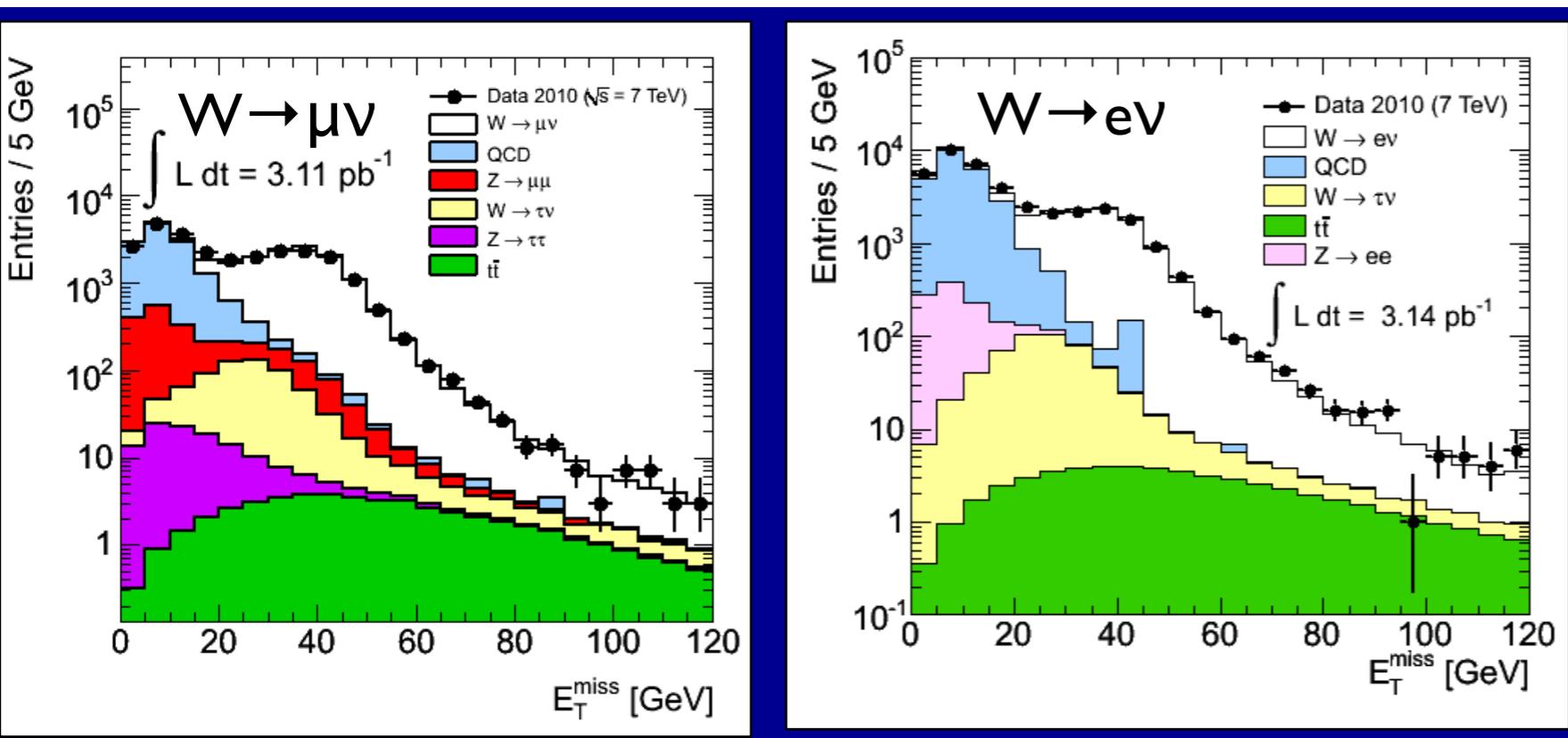


- $Z \rightarrow ll$ for calibration of the detector to the ultimate precision
- Tag/Probe for trigger/ID eff
- Among backgrounds to searches for New Physics

WYield

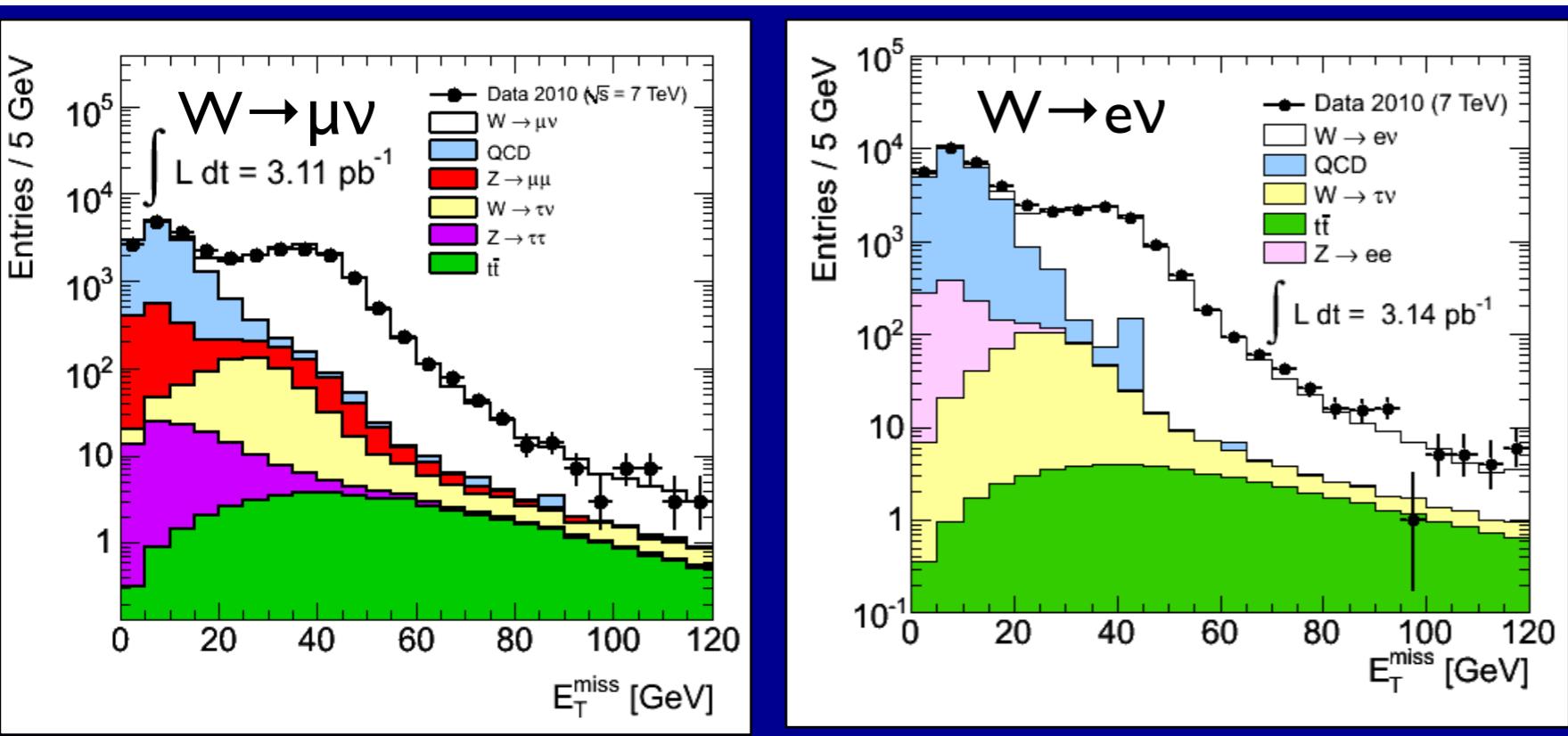
W Yield

After Good Lepton Requirement

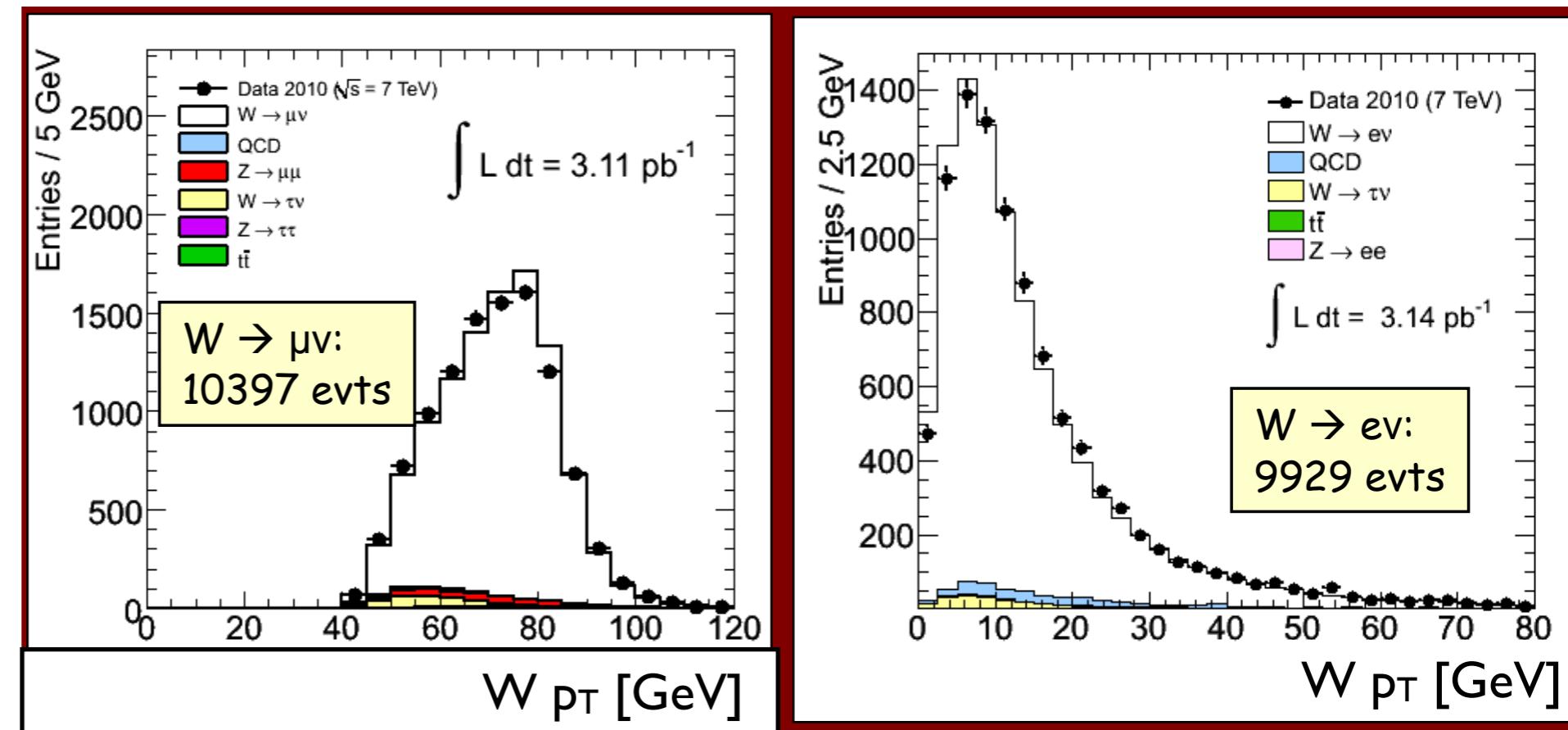


W Yield

After Good Lepton Requirement



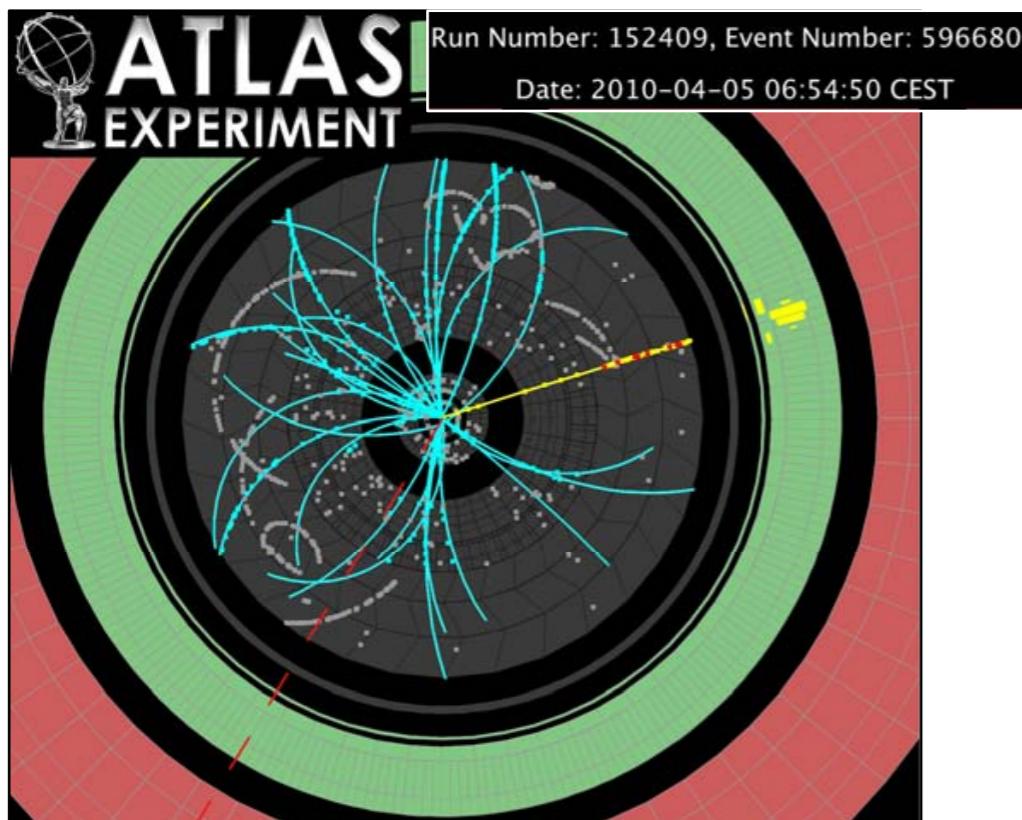
After all cuts



W Details

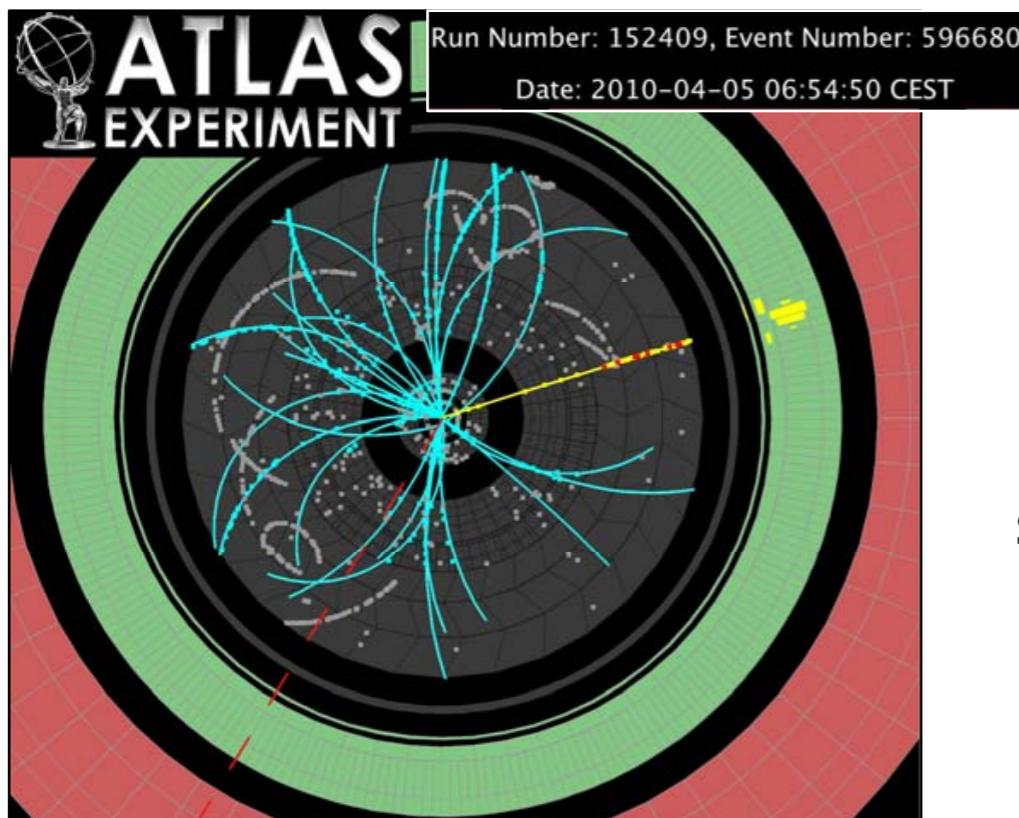
W Details

- $W \rightarrow e\nu$:
 - $E_T(e) > 20 \text{ GeV}$
 - $|\eta| < 2.47$
 - Tight electron
 - $E_T^{\text{miss}} > 25 \text{ GeV}$
 - Transverse mass $m_T > 40 \text{ GeV}$
 - Acceptance \times efficiency: $\sim 30\%$
 - Expected S/B: ~ 15 Main
 - Backgrounds: $W \rightarrow \tau\nu$, QCD jets

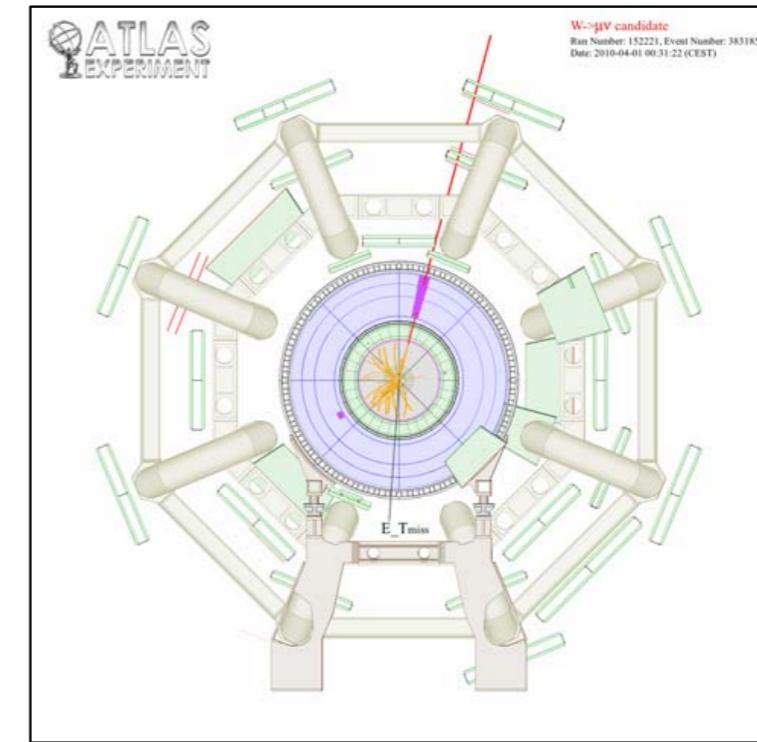


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 - Acceptance x efficiency: $\sim 30\%$
 - Expected S/B: ~ 15 Main
 - Backgrounds: $W \rightarrow \tau\nu$, QCD jets
- $W \rightarrow \mu\nu$:
 - $p_T(\mu) > 20 \text{ GeV}$
 - $|\eta| < 2.4$
 - $|\Delta p_T (\text{ID-MS})| < 15 \text{ GeV}$
 - Isolated; $|Z_\mu - Z_{\text{vtx}}| < 1 \text{ cm}$
 - $E_T^{\text{miss}} > 25 \text{ GeV}$
 - Transverse mass $m_T > 40 \text{ GeV}$
 - Acceptance x efficiency: $\sim 35\%$
 - Expected S/B ~ 10
 - Main backgrounds : $Z \rightarrow \mu\mu W \rightarrow \tau\nu$



QCD
background
estimation:
several methods
used, mostly
data-driven

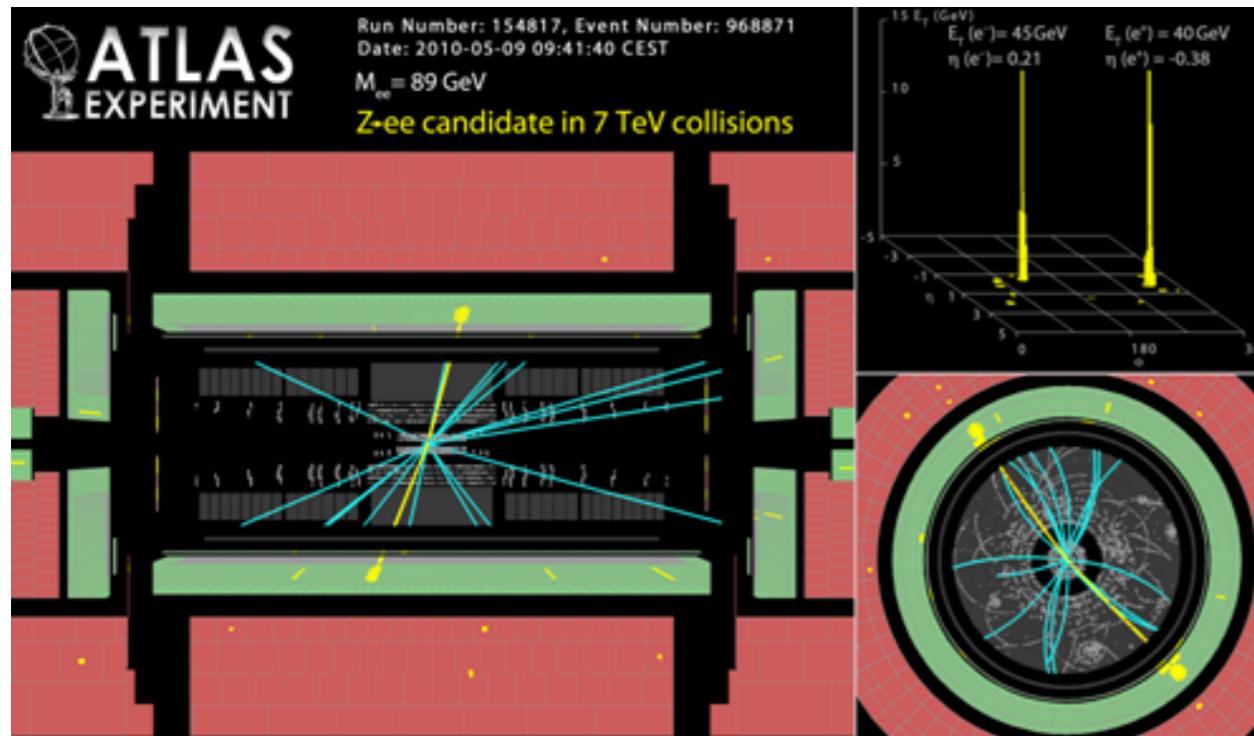


$\sim 3/\text{pb}$

Z Details/Yield

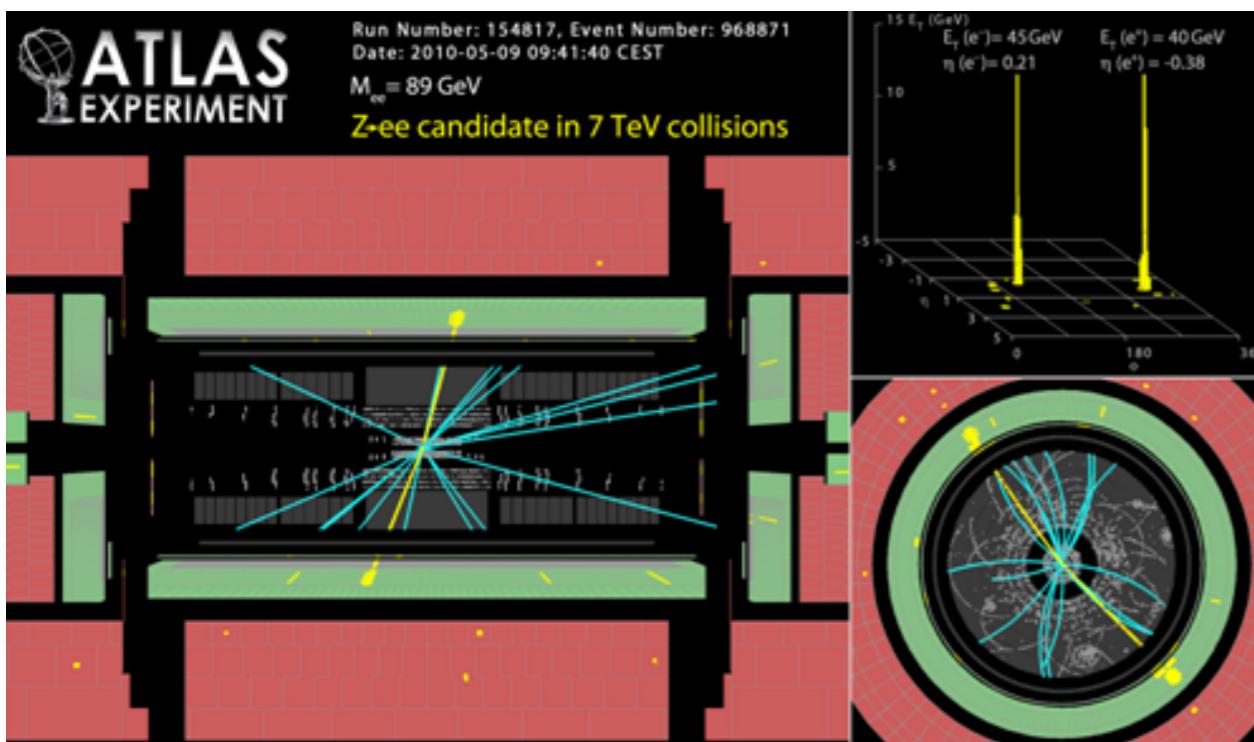
Z Details/Yield

- $Z \rightarrow ee$:
 - 2 opposite-sign electrons
 - $E_T > 20 \text{ GeV}$
 - $|\eta| < 2.47$
 - medium electron
 - $66 < M(e^+e^-) < 116 \text{ GeV}$
 - Acceptance \times efficiency : $\sim 30\%$
 - Expected S/B ~ 100
 - Main background: QCD jets

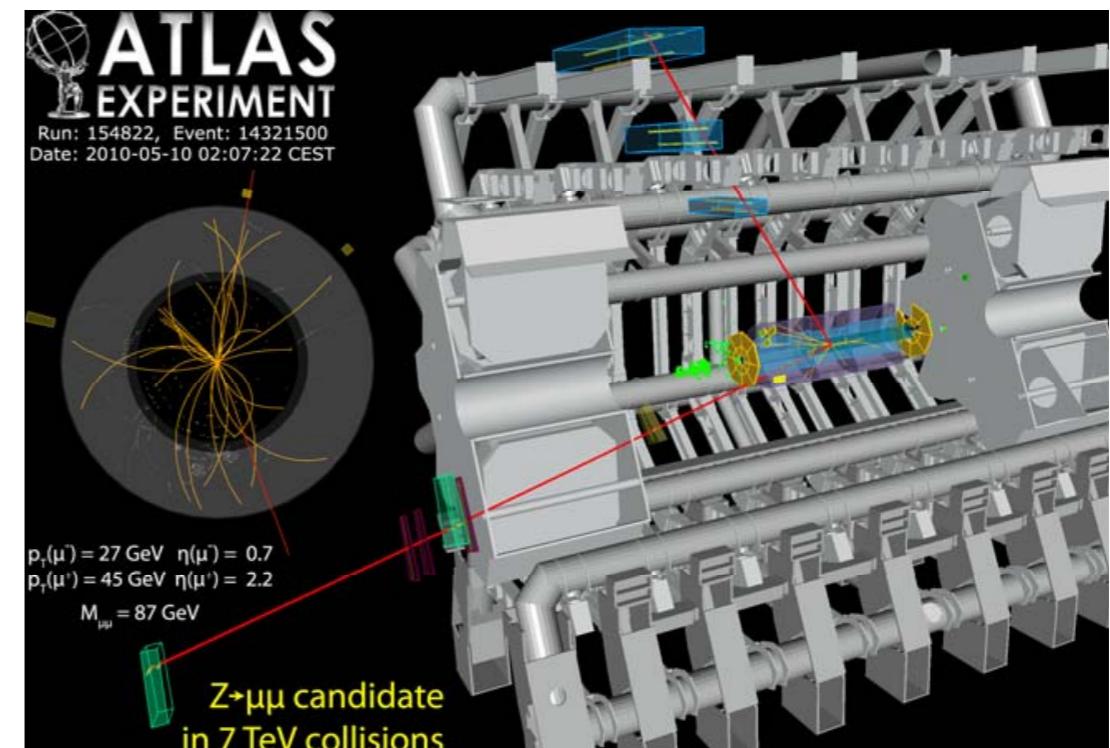


Z Details/Yield

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 - Main background: QCD jets



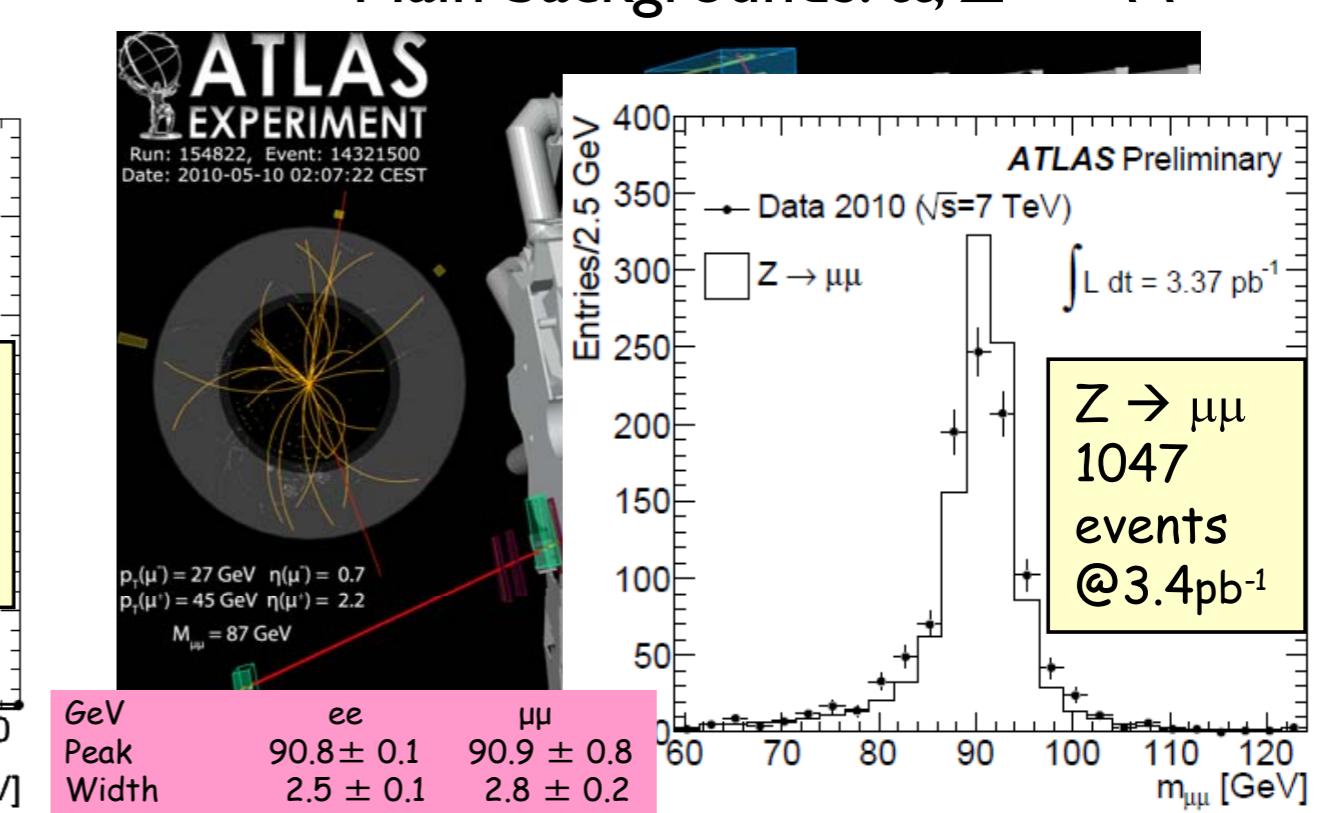
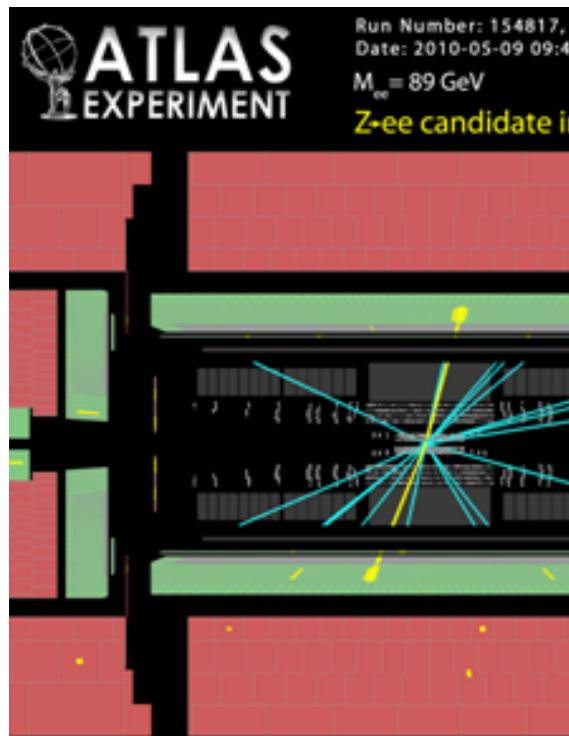
- $Z \rightarrow \mu\mu$:
 - 2 opposite-sign muons
 - $p_T > 20 \text{ GeV}$
 - $|\eta| < 2.4$
 - $|\Delta p_T (\text{ID-MS})| < 15 \text{ GeV}$
 - isolated; $|Z_\mu - Z_{\text{vtx}}| < 1 \text{ cm}$
 - $66 < M(\mu^+\mu^-) < 116 \text{ GeV}$
 - Acceptance x efficiency: $\sim 35\%$
 - Expected S/B > 100
 - Main backgrounds: tt, $Z \rightarrow \tau\tau$



$\sim 3/\text{pb}$

Z Details/Yield

- $Z \rightarrow ee$:
 - 2 opposite-sign electrons
 - $E_T > 20 \text{ GeV}$
 - $|\eta| < 2.47$
 - medium electron
 - $66 < M(e^+e^-) < 116 \text{ GeV}$
 - Acceptance x efficiency : $\sim 30\%$
 - Expected S/B ~ 100
 - Main background: QCD jets



Top

Top

- Lepton + Jets:
 - $t\bar{t} \rightarrow bW bW \rightarrow b\ell\nu bjj$
 - $\sigma \sim 70 \text{ pb}$
 - 1 isolated lepton $p_T > 20 \text{ GeV}$
 - $E_T^{\text{miss}} > 20 \text{ GeV}$
 - ≥ 4 jets $pT > 20 \text{ GeV}$
 - ≥ 1 b-tag jet
 - Acceptance \times efficiency $\sim 30\%$
 - 280/nb expected: 5 signal events

$$|\sigma(t\bar{t})| \approx 160 \text{ pb} \quad \sqrt{s} = 7 \text{ TeV}$$

Top

- Lepton + Jets:
 - $t\bar{t} \rightarrow bW bW \rightarrow blv bjj$
 - $\sigma \sim 70 \text{ pb}$
 - 1 isolated lepton $p_T > 20 \text{ GeV}$
 - $E_T^{\text{miss}} > 20 \text{ GeV}$
 - ≥ 4 jets $p_T > 20 \text{ GeV}$
 - ≥ 1 b-tag jet
 - Acceptance x efficiency $\sim 30\%$
 - $280/\text{nb}$ expected: 5 signal events
- Di Lepton:
 - $t\bar{t} \rightarrow bW bW \rightarrow blv blv$
 - $\sigma \sim 10 \text{ pb}$
 - 2 opposite ee, e μ , $\mu\mu$
 - both leptons $p_T > 20 \text{ GeV}$
 - ≥ 2 Jets $p_T > 20 \text{ GeV}$
 - ee: $E_T^{\text{miss}} > 40 \text{ GeV}, |M(ee) - M_Z| > 5 \text{ GeV}$
 - $\mu\mu$: $E_T^{\text{miss}} |M(\mu\mu) - M_Z| > 10 \text{ GeV}$
 - e μ : $H_T = \sum E_T(\text{leptons, jets}) > 150 \text{ GeV}$
 - Acceptance x efficiency $\sim 25\%$
 - $280/\text{nb}$ expected: 0.7 signal events

$$|\sigma(t\bar{t})| \approx 160 \text{ pb} \quad \sqrt{s} = 7 \text{ TeV}$$

Top

- Lepton + Jets:
 - $t\bar{t} \rightarrow bW bW \rightarrow blv bjj$
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 - e μ : $H_T = \sum E_T(\text{leptons, jets}) > 150 \text{ GeV}$
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 - 280/nb expected: 0.7 signal events

ID	Run number	Event number	Channel	p_T^{lep} (GeV)	E_T^{miss} (GeV)	m_T (GeV)	m_{jjj} (GeV)	#jets $p_T > 20 \text{ GeV}$	#b-tagged jets
LJ1	158801	4645054	$\mu + \text{jets}$	42.9	25.1	59.3	314	7	1
LJ2	158975	21437359	$e + \text{jets}$	41.4	89.3	68.7	106	4	1
LJ3	159086	12916278	$e + \text{jets}$	26.2	46.1	62.6	94	4	1
LJ4	159086	60469005	$e + \text{jets}$	39.1	66.7	102	231	4	1
LJ5	159086	64558586	$e + \text{jets}$	79.3	43.4	86.7	122	4	1
LJ6	159224	13396261	$\mu + \text{jets}$	29.4	65.4	64.1	126	5	1
LJ7	159224	13560451	$\mu + \text{jets}$	78.7	40.0	83.7	108	4	1

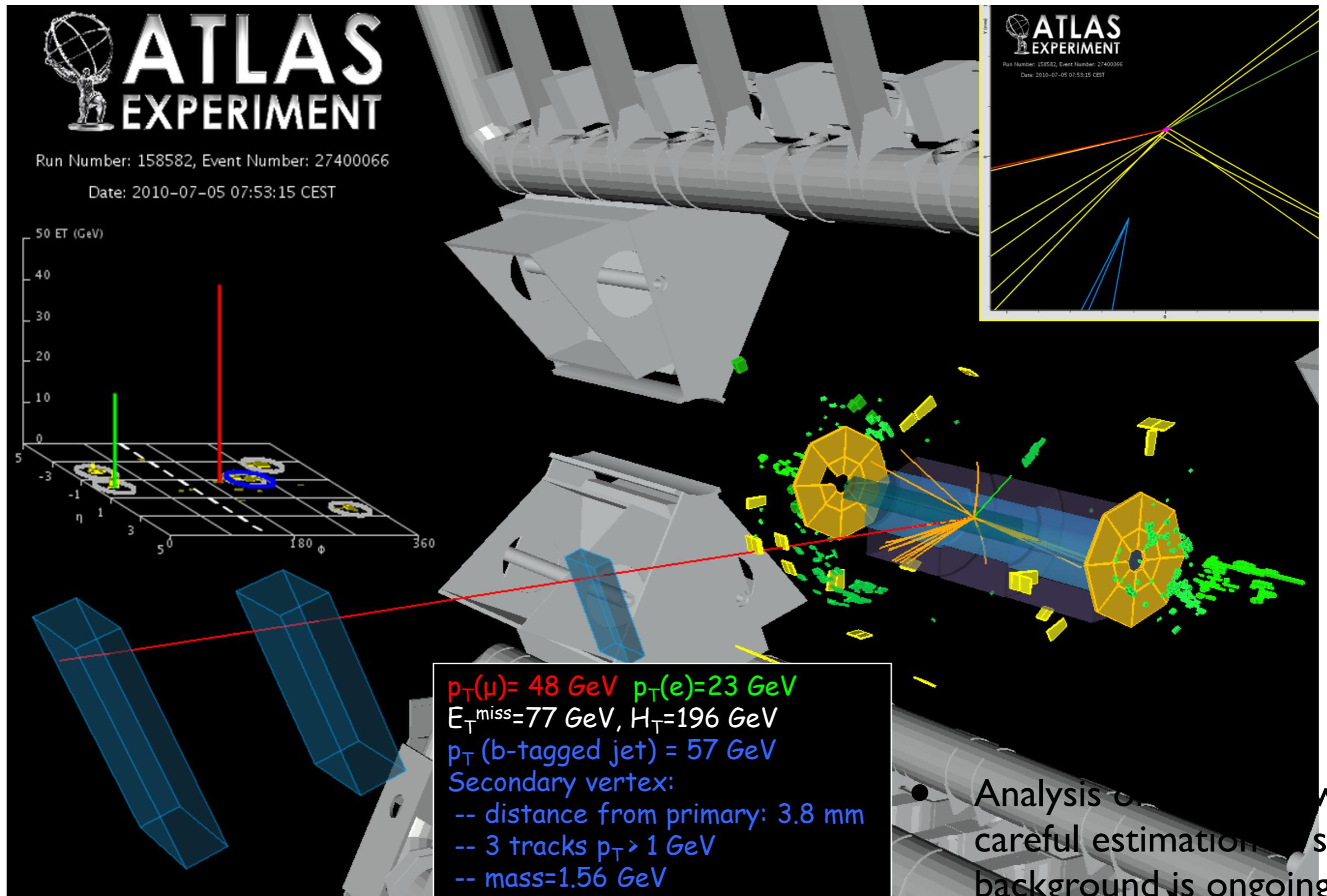
ID	Run number	Event number	Channel	p_T^{lep} (GeV)	E_T^{miss} (GeV)	H_T (GeV)	#jets $p_T > 20 \text{ GeV}$	#b-tagged jets
DL1	155678	13304729	ee	55.2/40.6	42.4	271	3	1
DL2	158582	27400066	$e\mu$	22.7/47.8	76.9	196	3	1

*Observed 9 candidates:
2 di-lepton and 7 lepton + Jets*

$$|\sigma(t\bar{t})| \approx 160 \text{ pb} \quad \sqrt{s} = 7 \text{ TeV}$$

Top eμ Candidate

Top e μ Candidate



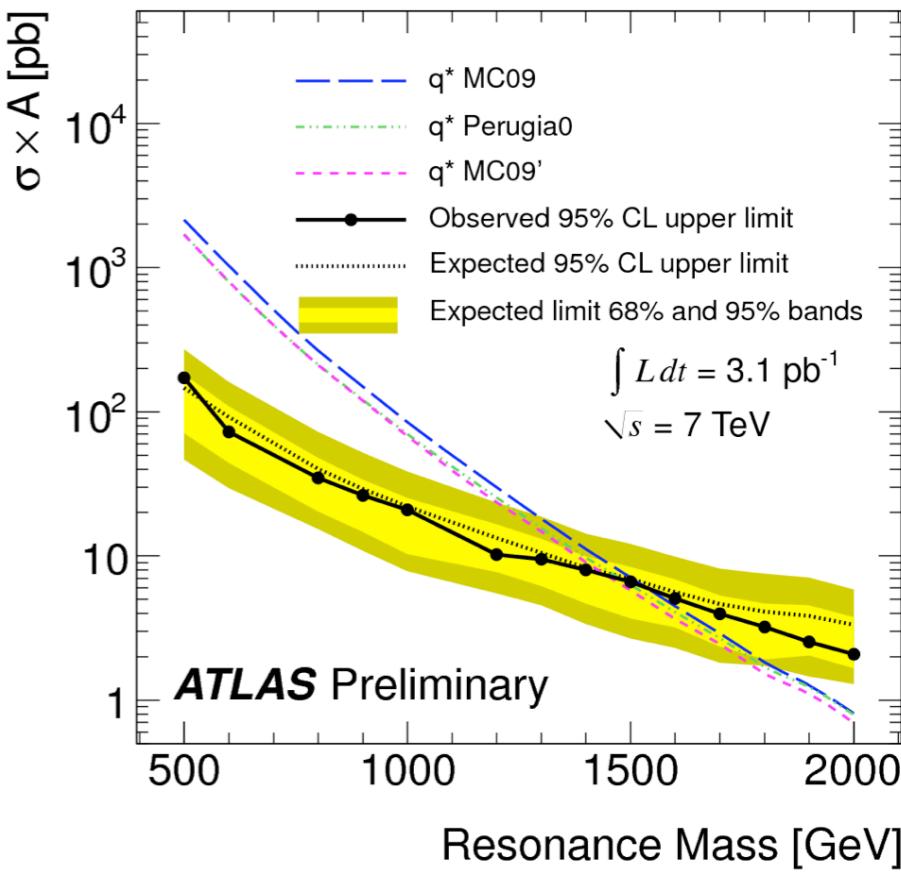
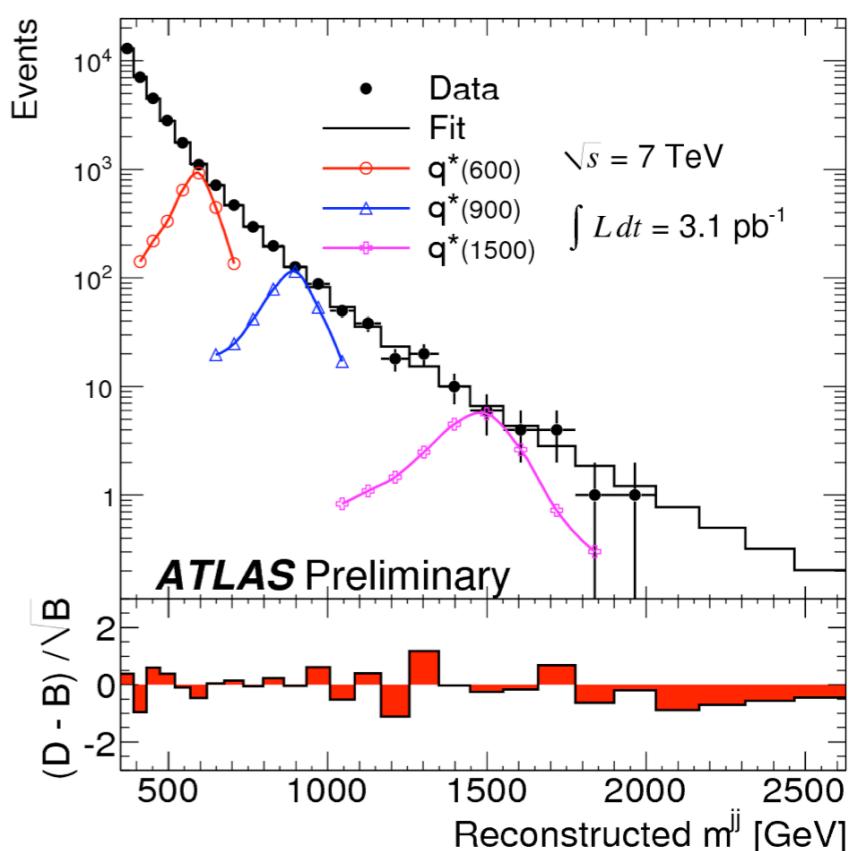
Search for New Physics

Excited Quarks

Excited Quarks

315/nb & 3.1/pb
 Phys. Rev. Lett. 105, 161801 (2010)
 ATLAS-CONF-2010-093

- *Bump hunt in dijet mass*
- Selection (315/nb and 3.1/pb):
 - $p_T^{1,2} > 80, 30 \text{ GeV}$
 - $|\eta^{1,2}| < 2.5$ and $|\Delta\eta| < 1.3$
- Mass resolution: 13% (6%) at 200 (1000) GeV
- q^* Model: $\mathcal{L}_{int.} = \frac{1}{2\Lambda} \bar{F}_R^* \sigma^{\mu\nu} \left[g f \frac{\tau^a}{2} W_{\mu\nu}^a + g' f' \frac{Y}{2} B_{\mu\nu} + g_s f_s \frac{\lambda^a}{2} G_{\mu\nu}^a \right] F_L + h.c.$
- Compositeness Scale: $\Lambda = m_{q^*}$
- $f, f', f_s = \text{coupling} = 1$
- $f_s \neq 0$ allows qg fusion production + dijet decays
- *PRL with 315/nb first published BSM from LHC*
- Beats CDF's $260 \text{ GeV} < m_{q^*} < 870 \text{ GeV}$ [Phys Rev D79 112002 (2009)]
- Conf note with 3.1/pb:
 - $400 \text{ GeV} < m_{q^*} < 1260 \text{ GeV}$



Dijet Angular Distributions

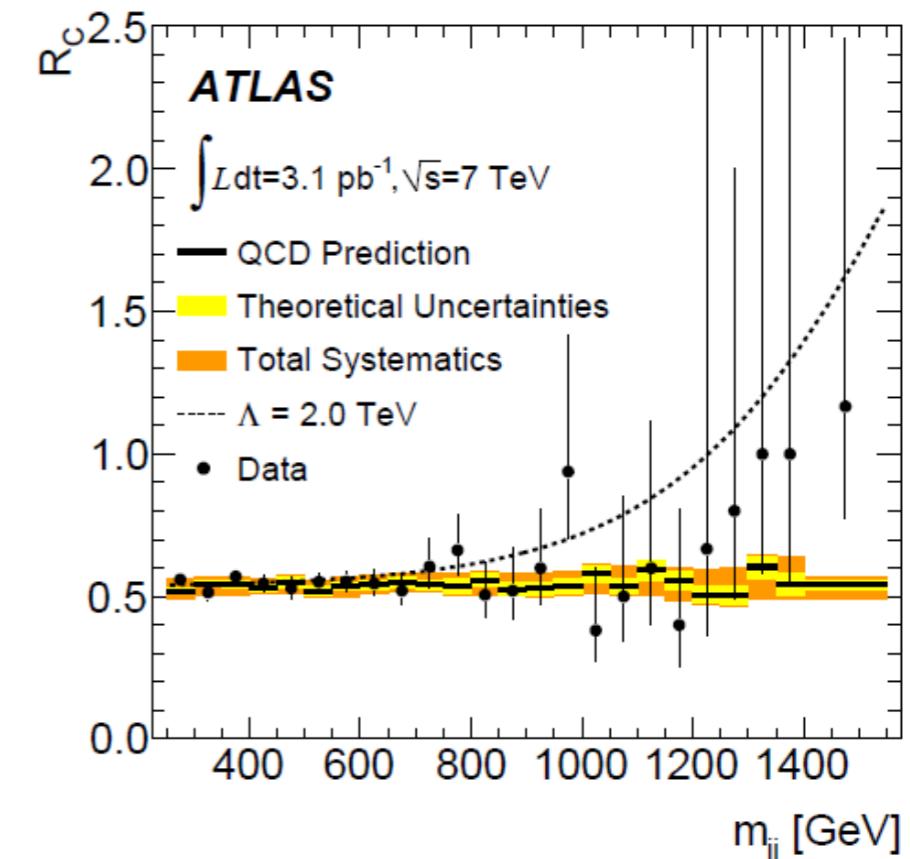
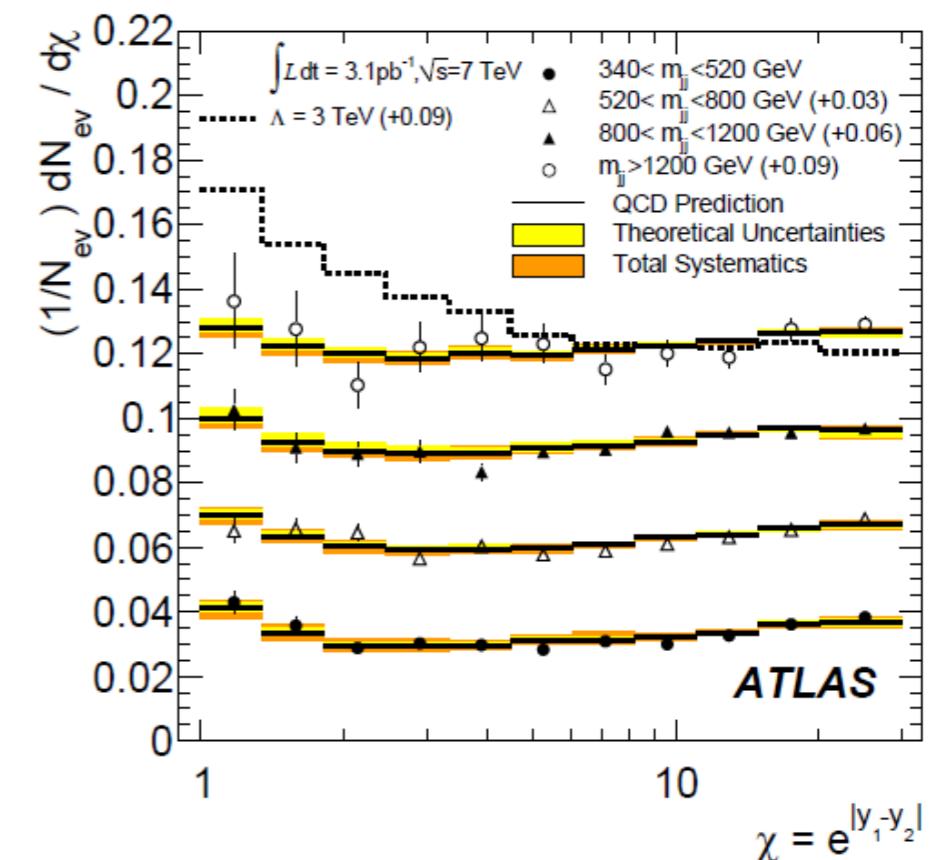
Dijet Angular Distributions

3.1/pb

arXiv:1009.5069

submitted to Phys. Lett. B

- Dijet angular distributions measured over a large angular range and with M_{jj} up to 2.8 TeV
- *Distributions are in good agreement with QCD predictions.*
- *Quark contact interactions 95% CL exclusion: $\Lambda > 3.4 \text{ TeV}$*

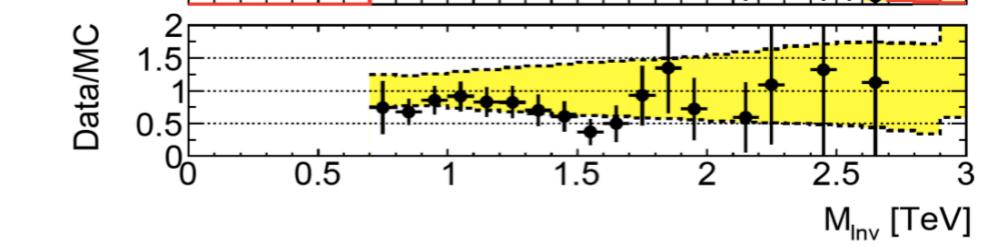
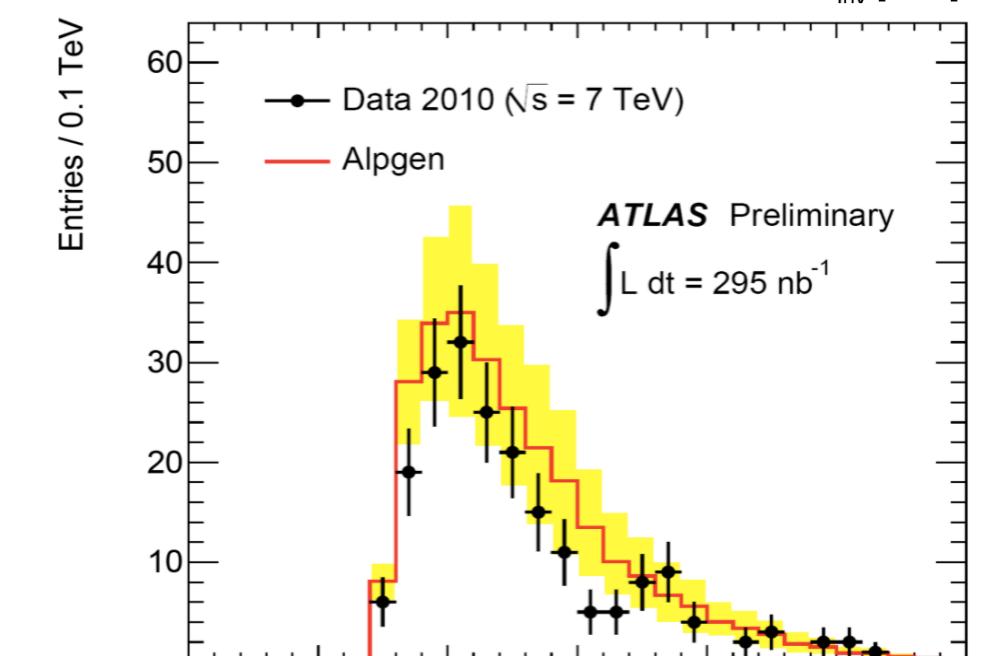
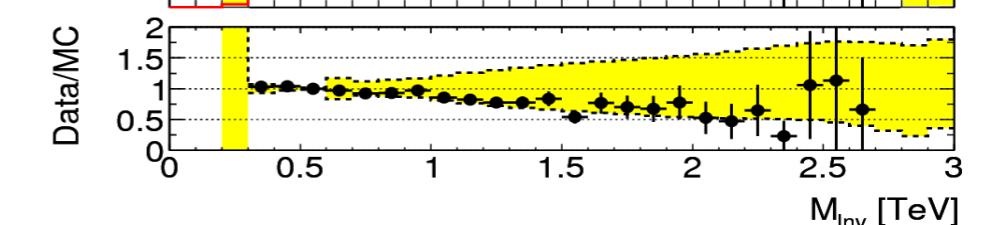
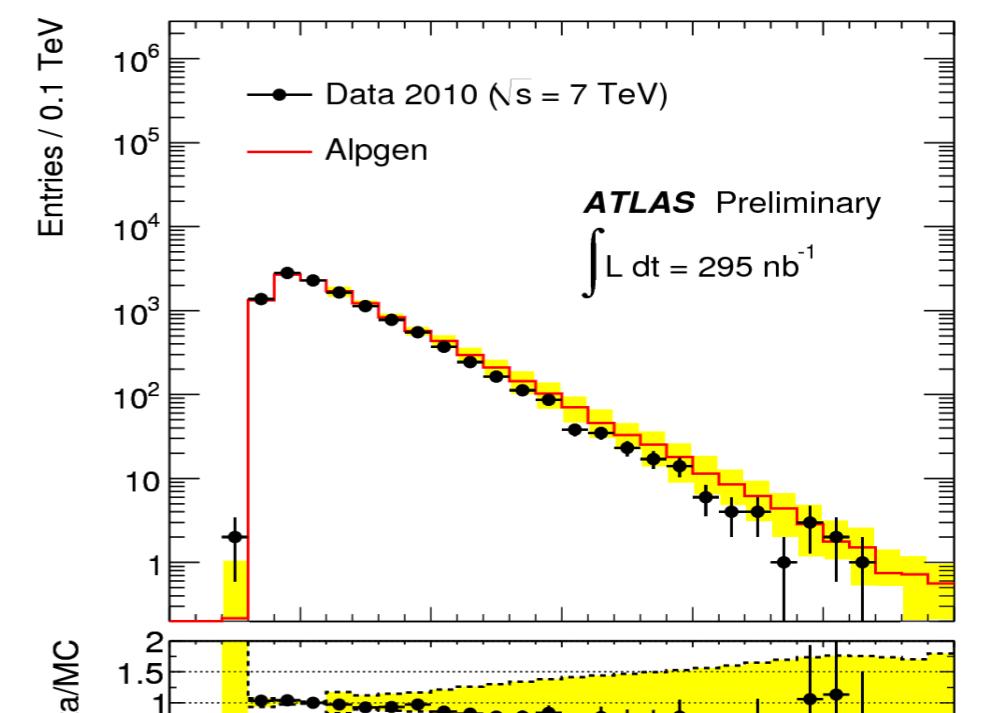


High Multiplicity Final States

High Multiplicity

Final States

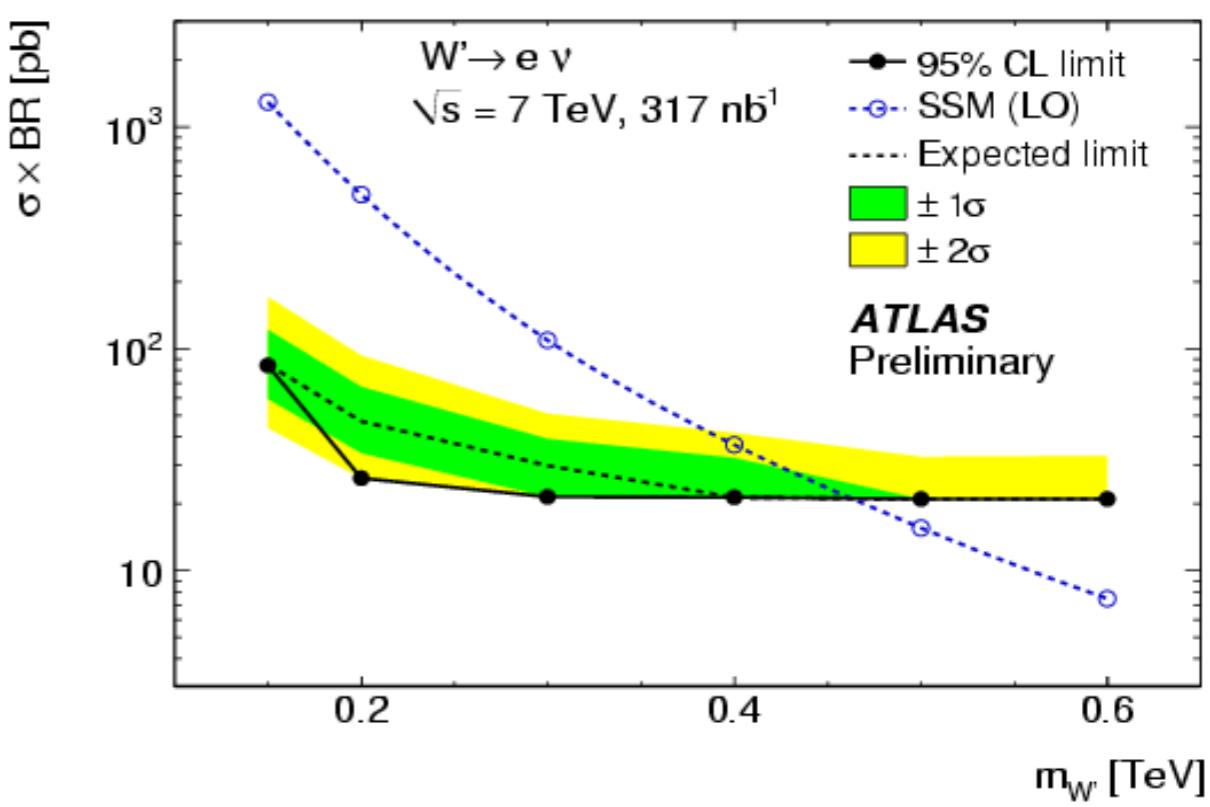
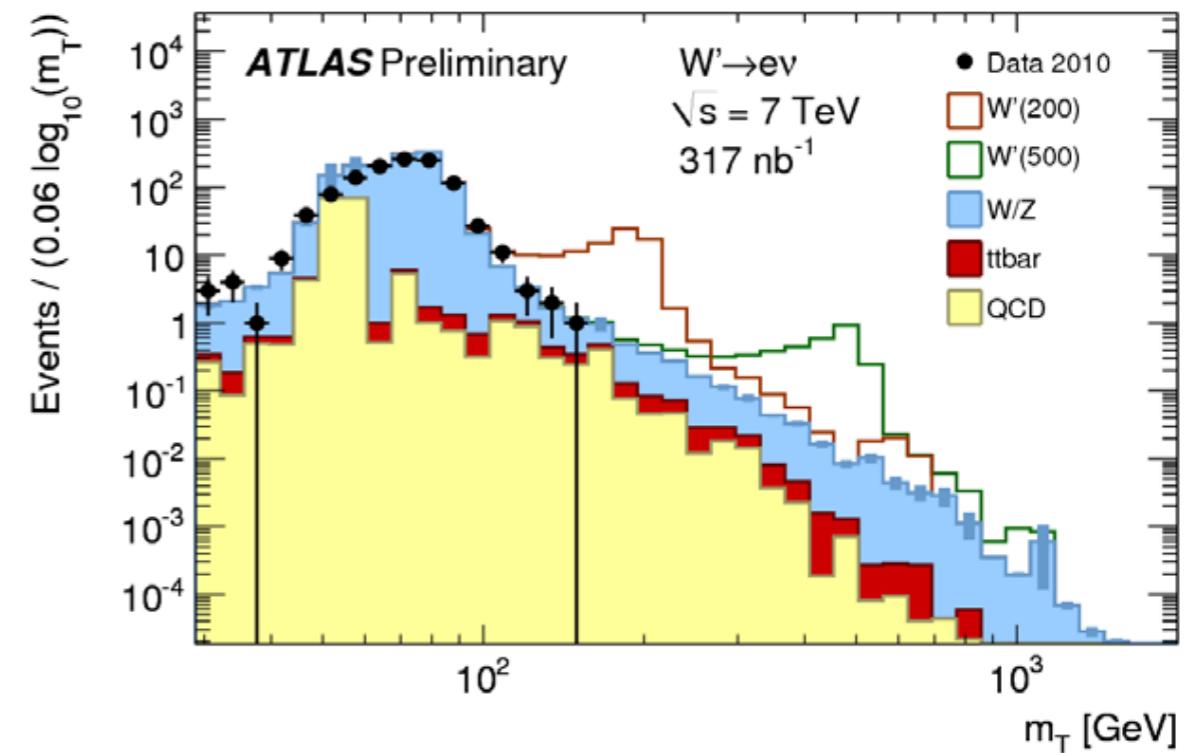
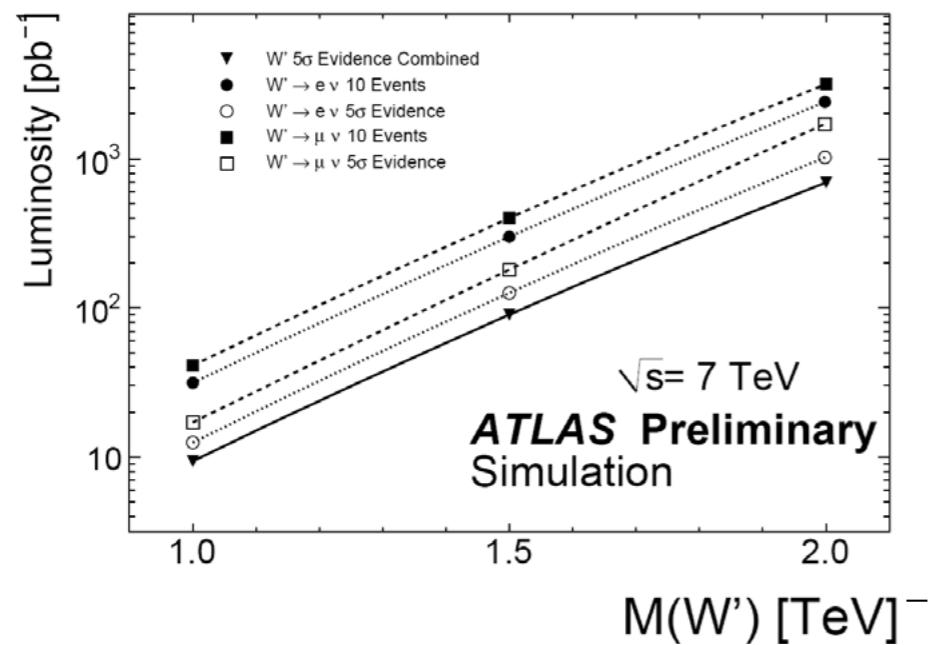
- Model Independent Search in final states with high multiplicity.
- Check invariant mass of $n \geq 3$ high p_T objects
 - Central Jets $p_T > 40$ GeV
 - $e/\gamma/\mu$ $p_T > 20$ GeV
- *Control Region*: normalize data to MC
 - $\sum p_T > 300$ GeV and $300 \text{ GeV} < M_{\text{inv}} < 800$ GeV
- *Signal Region*: look for deviations
 - $\sum p_T > 700$ GeV and $M_{\text{inv}} > 800$ GeV
- *No deviation from SM*
- Upper limit (95% C.L.):
 - $\sigma \times \text{Acceptance} = 0.34$ nb



W'

W'

- Fermilab: $m_{W'} > 1 \text{ TeV}$
 - assuming the same couplings as those for the Standard Model W
- Same data/analysis as W production
- *Good agreement of mass tail with MC*
- We can extend sensitivity around 5/pb
- *Discovery potential at 10-20/pb*



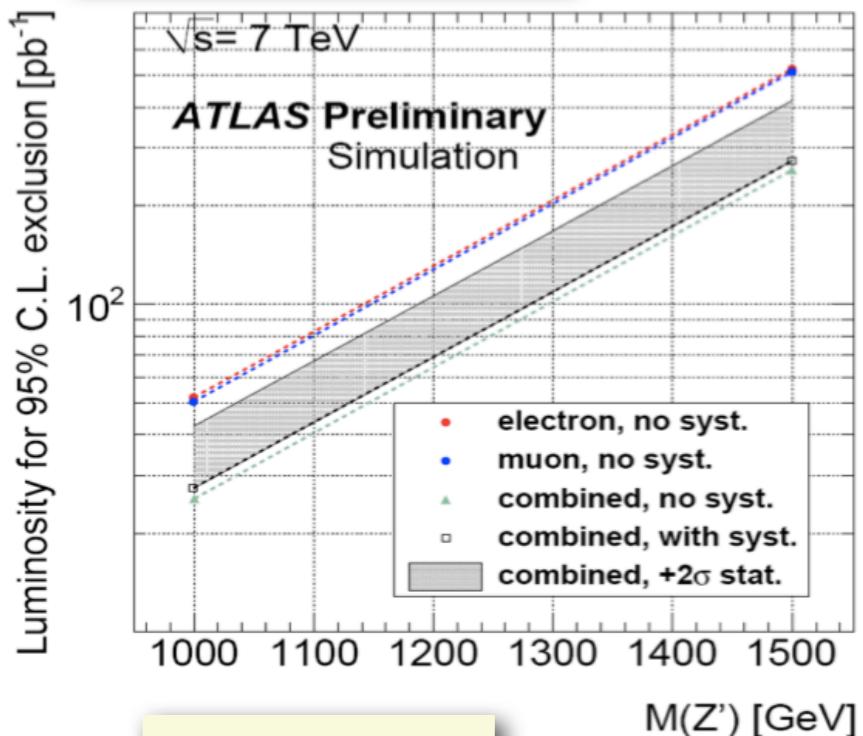
Z'

Z'

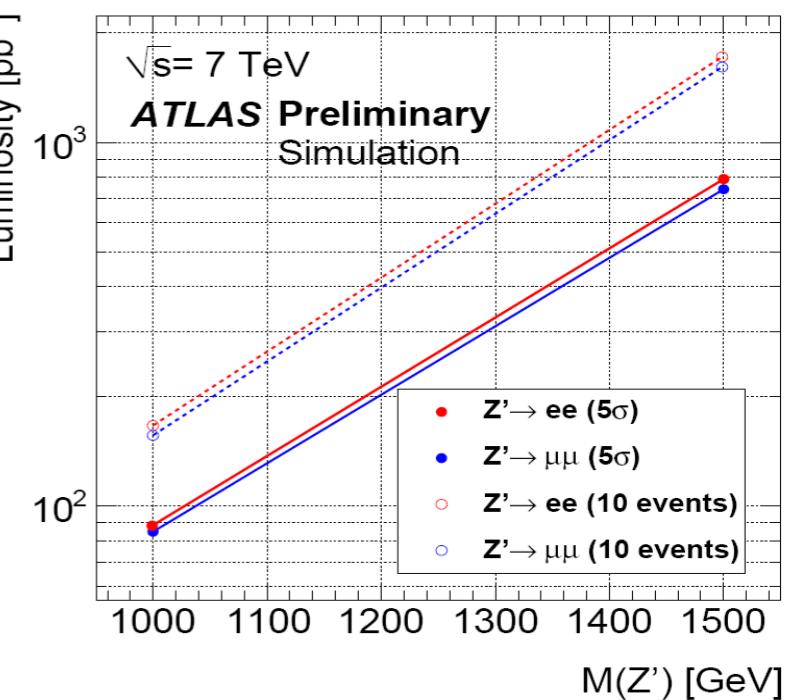
MC only

- Fermilab $M_{Z'} > 1 \text{ TeV}$
- Expected exclusion:
 - $100/\text{pb} \sim 1.3 \text{ TeV}$
 - $1/\text{fb} \sim 1.8 \text{ TeV}$
- $100/\text{pb}$ sufficient for discovery of $M_{Z'} = 1 \text{ TeV}$

... an exclusion at 95% CL:



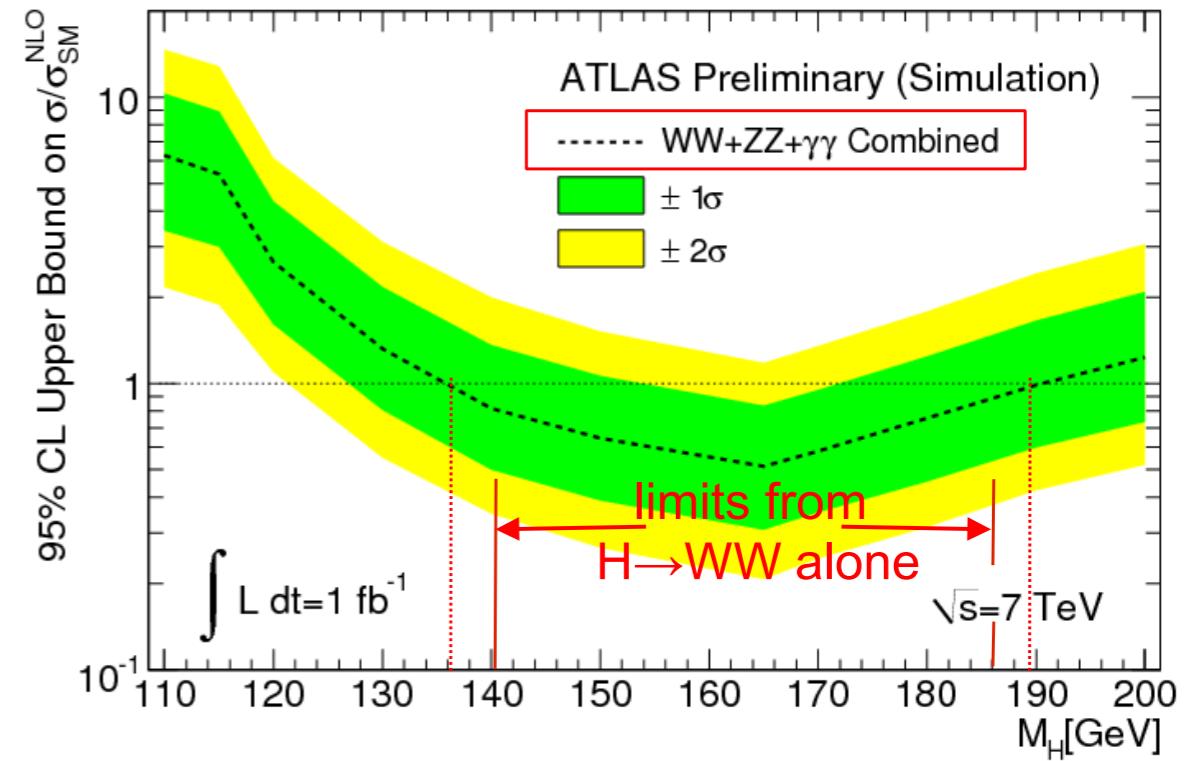
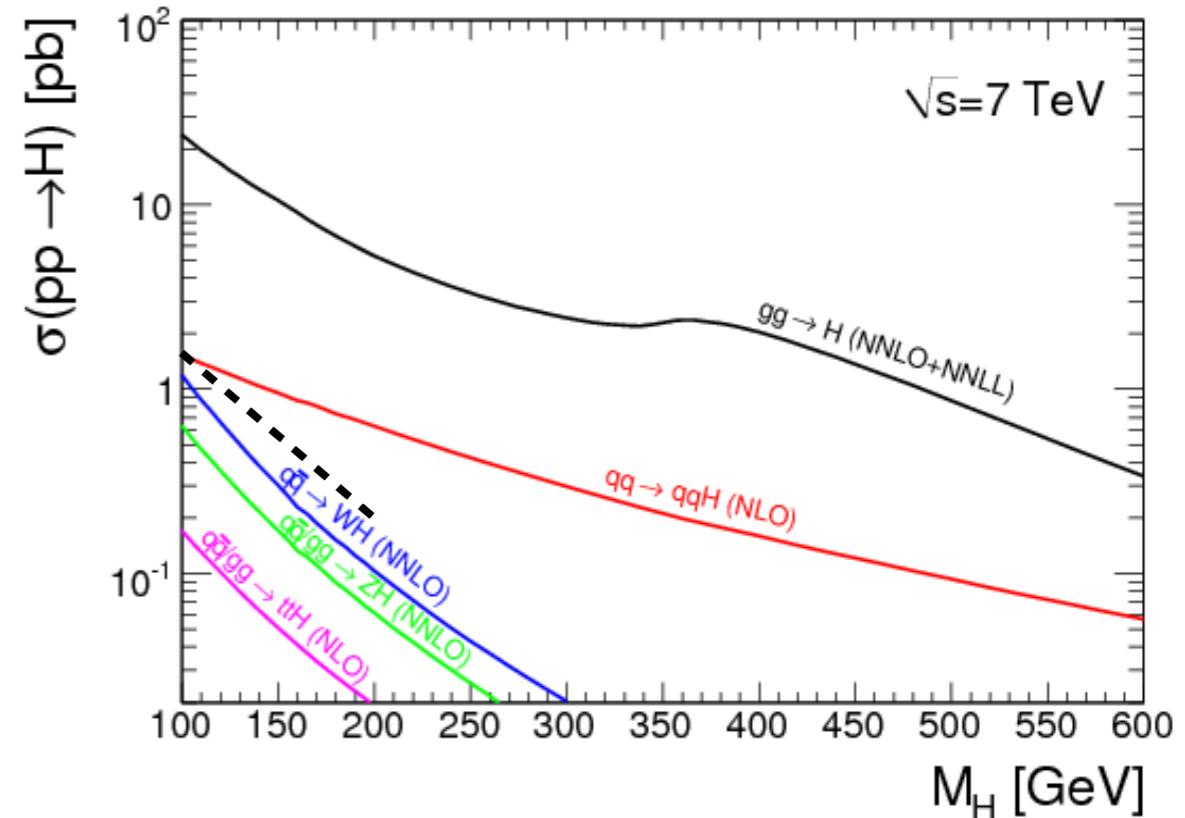
... a Z' discovery:



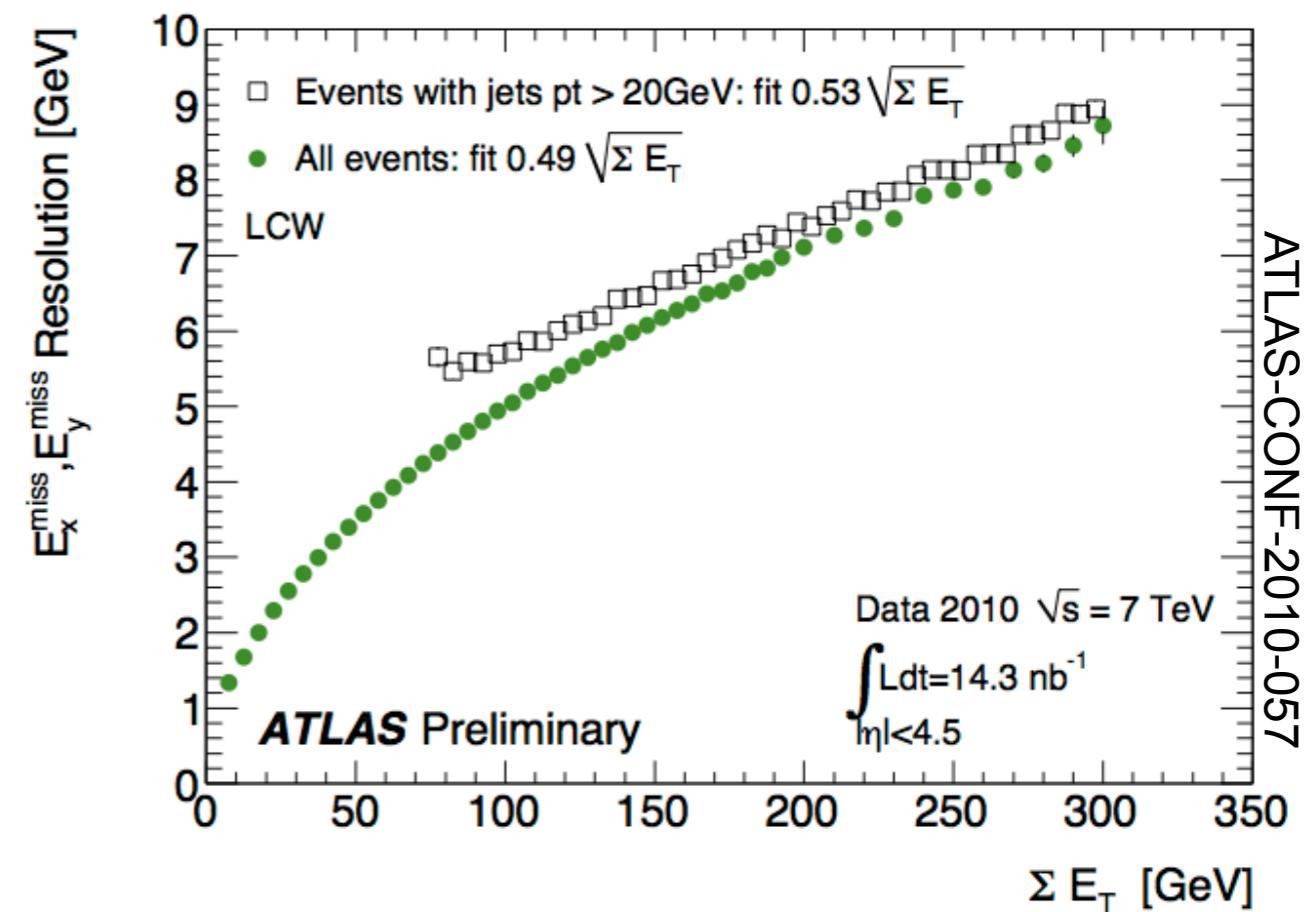
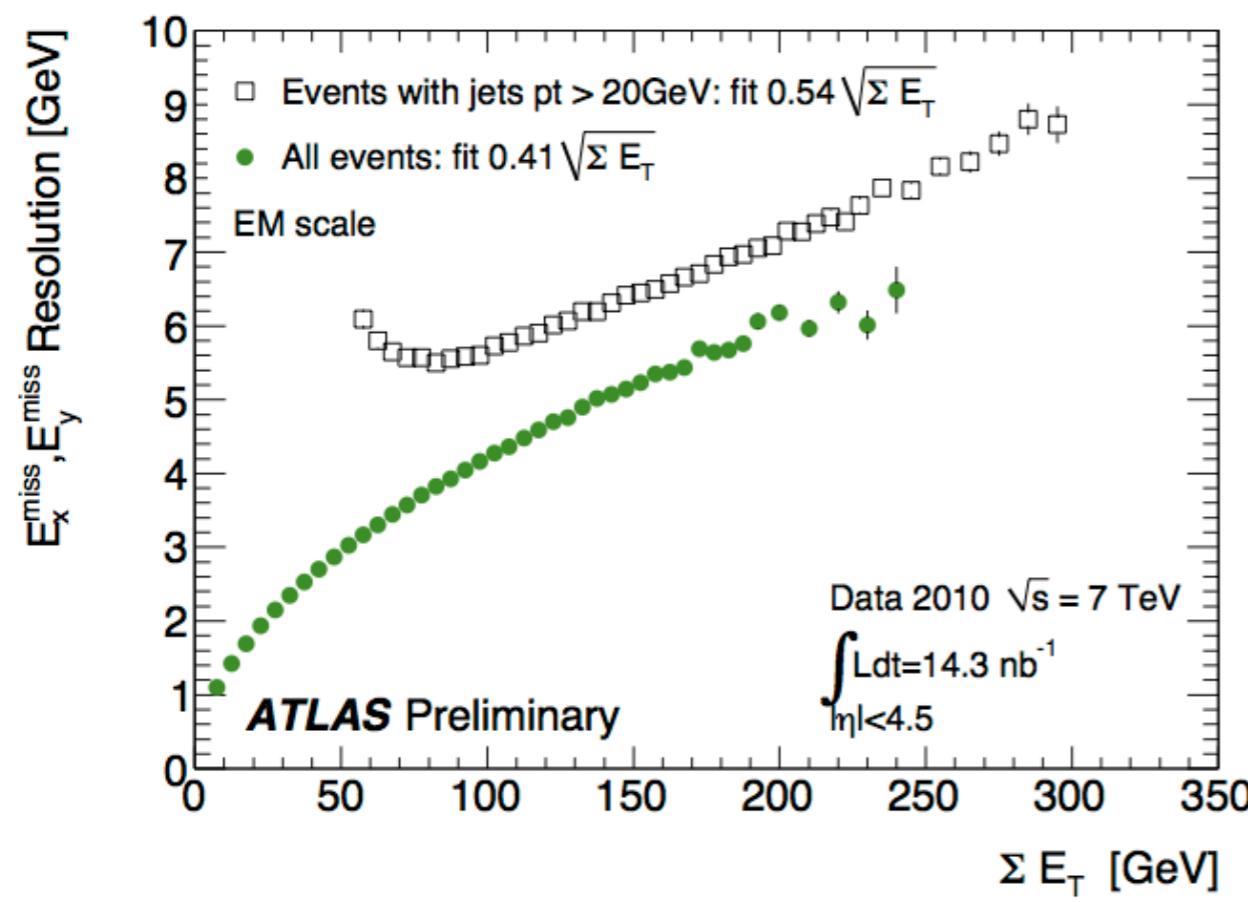
Higgs Potential

Higgs Potential

- Factor of 10 advantage in H production x-section over TeVatron
- Combination of $\gamma\gamma$, ZZ, and WW channels
 - $M_H < 130$ GeV $\gamma\gamma$ contributes
 - $130 < M_H < 200$ GeV Limit dominated by WW
 - $M_H > 200$ GeV Limit based on ZZ
- Expected 1/fb 95% Exclusion:
 - $135 < M_H < 188$ GeV
 - bb and tt channels will improve low mass sensitivity
 - Can push BSM Higgs limits at 100/pb.



MET with high pT Jets



Keeping Perspective

- SUSY has served as a framework for building search strategies... but it's a double edged sword:
 - SUSY's large parameter space provides a wide range of phenomenologies
 - but we must reduce number of dimensions to do manageable scans
 - the SUSY break models have been the primary reduction mechanism
- So there has been a historical reliance on SUSY models like mSUGRA
- There is also a historical separation of searches into SUSY and Exotics
- While SUSY is very compelling, the broader interest is in finding deviations from SM.
- Our primary motivations are hierarchy problem and dark matter.
 - both point to new (hopefully related) TeV scale phenomena
 - If we observe a deviation, it'll take some time to characterize it sufficiently to be able to pin down the underlying theory... we will not call it SUSY.
 - Even though we say we are looking for SUSY and put limits on SUSY parameters, we know we shouldn't be hung up on SUSY at this stage of the game...
 - Hopefully our search strategies and interpretation of results will reflect this view in next the year... but not in the next set of results